SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

BIM – Continuous workflow for integrated lighting solutions and underlying data

T70.C.3 – A Technical Report of Subtask C



IEA SHC TASK 70 | EBC Annex 90: LOW CARBON, HIGH COMFORT INTEGRATED LIGHTING

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BIM – Continuous workflow for integrated lighting solutions and underlying data

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PREFACE

Lighting accounts for approximately 15% of the global electric energy consumption and 5% of greenhouse gas emissions. Growing economies, higher user demands for quality lighting and rebound effects as a result of low priced and more versatile electric lighting continuously still lead to an absolute increase of lighting energy consumption. More light is used, often less consciously.

Especially the electric lighting market but as well the façade, daylighting und building automation sectors have seen significant technological developments in the past decade. However, these sectors still act mainly independent of each other, leaving out big potentials lying in a better technology and market integration. This integration is on the one hand beneficial to providing better user-centred lighting of indoor spaces. On the other hand, it can contribute significantly to the reduction of worldwide electricity consumptions and CO_2 emissions, which is in line with several different governmental energy efficiency and sustainability targets.

IEA SHC Task 70 “Low Carbon, High Comfort Integrated Lighting” therefore pursues the goal to support and foster the better integration of electric lighting and daylighting systems including lighting controls with a main focus on the non-residential sector. This includes the following activities:

- Review relation between user perspective (needs/acceptance) and energy in the emerging age of “smart and connected lighting” for a relevant repertory of buildings.
- Consolidate findings in use cases and “personas” reflecting the behaviour of typical users.
- Based on a review of specifications concerning lighting quality, non-visual effects as well as ease of design, installation and use, provision of recommendations for energy regulations and building performance certificates.
- Assess and increase robustness of integrated daylight and electric lighting approaches technically, ecologically and economically.
- Demonstrate and verify or reject concepts in lab studies and real use cases based on performance validation protocols.
- Develop integral photometric, user comfort and energy rating models (spectral, hourly) as pre-normative work linked to relevant bodies: CIE, CEN, ISO. Initialize standardization.
- Provide decision and design guidelines incorporating virtual reality sessions. Integrate approaches into wide spread lighting design software.
- Combine competencies: Bring companies from electric lighting and façade together in workshops and specific projects. Hereby support allocation of added value of integrated solutions in the market.

To achieve this goal, the work plan of IEA SHC Task 70 is organized according to the following four main subtasks:

- Subtask A: Low Carbon Lighting and Passive Solar: Scenarios, Strategies, Roadmaps
- Subtask B: Visual and non-visual requirements
- Subtask C: Digitalized Lighting Solutions (Technology & Design Tools / Process)
- Subtask D: Application and Case Studies

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1 Executive Summary

Designing comfortable, low-energy buildings depends on connecting a shared digital building model with the right analysis tools. Building Information Modelling (BIM) acts as the common data backbone, but it must link smoothly to energy and lighting simulations and life-cycle assessment (LCA) to support reliable, sustainable decisions from early design through operation. Bringing these worlds together – BIM, energy and lighting analysis, LCA, and operational “digital twins” – is essential to improve planning quality, trust in results, and real-world performance.

State-of-the-art BIM workflows for integrated lighting solutions combining electric lighting, daylighting and lighting controls, are investigated. As an example of a practical solution, a standardized "BIM-to-BEM" workflow called BIM2BEM-Flow, is described. It combines a central parameter server and workflow managers with a Revit plug-in to define responsibilities, harmonize names and units, set sensible defaults, run pre-export checks, and automate openBIM Industry Foundation Classes (IFC) exports. This reduces manual rework and closes the gap between design intent and what buildings actually deliver. The plug-in also automates parameter mapping, unit conversion, and validation so simulation tools receive the data they need in the right format.

Among today’s biggest hurdles are data handover interfaces between trades involved in the construction process: different tools speak different “dialects”, many simulation tools don’t fully read open standards (such as IFC), and non-geometric (alphanumeric) data is often lost. Until standards catch up, flexible, tool-aware mappings are needed to avoid errors and delays. Clear governance, i.e., who provides which data, when, and in what quality, also matters in an industry with a fragmented supply chain. A clearly defined data structure is necessary not only for data handover between trades or software tools. Standardisation is also necessary to be able to specify in tenders which data must be provided, or to find relevant data records in databases. International standardisation bodies are already addressing this. The key approaches for parameter specifications and existing or new, proposed standards are described, and the approaches and challenges involved in providing BIM data and product databases are discussed.

2 Introduction

By David Geisler-Moroder, Sascha Hammes

Building Information Modeling (BIM) has established itself as the central data and collaboration infrastructure of the construction industry. BIM integrates geometric and semantic information and supports coordinated processes across design, construction, and operations. In doing so, it addresses efficiency gaps, improves the quality of decision-making, and opens up new opportunities for data-driven collaboration [2:1, 2:2]. From a strategic perspective, BIM shifts value creation toward integrated, performance-oriented processes and forms the basis for analytics, automation, and subsequent operational optimization. Nevertheless, BIM alone does not fully meet the requirements of performance-based assessments. Reliable statements regarding energy demand, comfort, and environmental impacts require interoperable links to specialized simulation and evaluation tools [2:3]. These include, in particular, building energy modeling (BEM), daylight and electric lighting simulations, and life cycle assessments (LCA).

Lighting has a significant impact on energy consumption as well as visual and thermal user comfort and circadian needs within a building. Lighting analyses embedded in BIM allow design decisions to be systematically evaluated at an early stage. Linkages to physically based models, such as *Radiance* for daylight simulation and evaluation, create a robust bridge between geometry, materiality, and performance metrics. Electric lighting additionally requires the representation of luminaires, photometric data, and control strategies, ideally coupled with shading and daylighting control. Integrated workflows can thus make conflicting goals between visual quality and energy consumption transparent. Outstanding challenges include the standardization of lighting parameters, the modeling of dynamic and integrated controls, and reliable interoperability between BIM, lighting simulation, and building operations.

In practice, BIM authoring systems, thermal energy simulations, lighting simulations, and life-cycle analysis often operate in separate software environments. This leads to redundant data processing, inconsistent parameter mapping, and discrepancies between design intent and simulation inputs. Studies point to the persistence of interoperability issues and data discontinuities throughout the life cycle. While the Industry Foundation Classes (IFC) schema provides a vendor-neutral basis for data exchange, it only partially addresses domain-specific requirements such as detailed control logic, dynamic systems, and operational states. Ontological approaches and linked data models increase semantic depth and machine readability, thereby complementing IFC-based modeling.

Parametric and generative methods establish performance goals early on and support the systematic exploration of the design space. Multi-criteria optimization enables trade-offs between energy, comfort, costs, and environmental impacts. Coupled workflows connect BIM with validated simulation environments such as *EnergyPlus* for thermal and electrical loads and *Radiance* for daylight, creating iterative feedback loops between design parameters and results. Full automation remains limited by heterogeneous data models, a lack of standardization, and imprecise parameter mappings.

Digital twins (DT) extend BIM into the operational phase. They link sensors, actuators, and building models via bidirectional data paths. This enables real-time monitoring, predictive analytics, and adaptive control. For lighting systems, this opens up prospects for demand- and user-centered control [2:4]. However, research shows that the semantically consistent integration of lighting controls and their standard representation in DTs is still in its infancy [2:5, 2:6]. During the operational phase, the integration of BIM with lighting operational data can also support maintenance, repair, and asset management [2:7].

Life cycle assessment (LCA) further enhances BIM-based workflows by enabling environmental assessment across all construction phases. Integrating LCA into BIM enables early assessment of the material and operational impacts of building components and systems. Remaining obstacles include inconsistent data structures, limited availability of standardized environmental data, and manual mapping of BIM objects to LCA databases. In particular, the latter severely limits automation and scalability [2:8]. Environmental Product Declaration (EPD)-based workflows and automated mapping procedures are considered key to scaling and robust integration into design and decision-making processes.

Technical feasibility faces organizational and cultural hurdles during implementation [2:9]. A lack of expertise, additional coordination requirements, and uncertain return on investment expectations hinder widespread

adoption. The fragmented value chain in the construction industry complicates end-to-end processes and the sharing of reliable data. Studies recommend a combination of measures including training, governance for data and model quality, and clear information delivery schedules.

The convergence of BIM, energy simulation, lighting analysis, LCA, and DTs is central to sustainable construction. Scalable implementation requires progress in these areas. Advances in these fields are crucial for improving the quality of planning and the reliability of simulation results, as well as for measurably enhancing ecological and user-related performance.

This report highlights and discusses the various aspects that can be supported by BIM when planning daylighting and electric lighting. Therefore, workflows and approaches existing in scientific literature for integrating lighting design into BIM-planning processes are highlighted. This includes the planning process for daylight and artificial lighting design, taking into account energy efficiency aspects, but also the area of integrated LCA in combination with daylight and artificial lighting design. Results from an Austrian research project to develop a new method for improved BIM parameter process management for use in the integrated daylight and artificial lighting planning process are presented and discussed as an example. The complex topic of data specification for mapping electric lighting and daylighting systems as well as controls in BIM is described. Finally, a brief overview of the status and challenges of BIM data and databases is given.

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3 BIM workflow(s)

By Martin Hauer, Josef Miller, Sascha Hammes

The integration of daylight and artificial lighting design within BIM workflows is a rapidly developing research field that seeks to improve energy efficiency, occupant comfort, and overall building performance. While BIM has become an industry standard in architecture, engineering, and construction (AEC), its potential for integrating lighting strategies remains not yet fully standardized in practice. Unlike structural, mechanical, and plumbing components, lighting design – especially in the context of dynamic, sensor-based controls – has not yet been fully incorporated into standard BIM workflows. The reviewed literature, including systematic studies on BIM-integrated lighting control strategies, highlights significant progress, existing limitations, and future research needs in this area [3:1,3:2].

Especially decisions for successful daylight- and energy planning of a building are strongly determined by their early-stage design (e.g., building orientation, building shape and window ratios). Thus, it is highly relevant that experts in these fields, particularly in facility management (FM) as representative for building operations, are involved from the beginning to contribute their ideas and thoughts in an early design process [3:2]. Nevertheless, difficulties in information exchange and multidisciplinary still hinder fully seamless communication in BIM-based workflows, despite existing interoperable approaches such as IFC, OpenBIM frameworks, and API-based data exchange solutions.

However, despite existing challenges, the complete representation of the trades of daylight and artificial light and energy performance and all associated workflows in BIM is desirable because this integration enables more coherent design solutions and improves planning quality through consistent, machine-readable manufacturer product data from early design phases. Digitized, transparent, traceable product-data workflows foster trust and accountability among stakeholders and help reduce the performance gap by better aligning design intent and simulation results with as-built and operational energy and lighting performance.

3.1 State of research on BIM-workflows for integral day- and artificial lighting design

3.1.1 The Role of BIM in Integrated Lighting Design

BIM serves as a centralized platform for interdisciplinary collaboration, allowing professionals from different fields, like architects, lighting designers, engineers, and facility managers, to work with a shared data model. The incorporation of daylighting and artificial lighting into BIM processes aims to improve the predictability, efficiency, and accuracy of lighting designs, particularly in relation to energy savings and visual comfort.

Recent BIM-driven lighting research focuses on connecting BIM authoring with daylight and electric-lighting simulators, adding parametric and optimization loops, and linking it with controls and IoT. While mature prototypes exist, cross-tool interoperability, control-data modelling, and validated whole-building artificial-lighting workflows remain limited still limited. The research emphasizes the necessity of developing consistent workflows that bridge the gap between conceptual lighting design, energy simulation, and real-world implementation in smart buildings [3:1].

3.1.2 Challenges in BIM-based Lighting Integration

Despite promising developments, several barriers hinder the full adoption of BIM-based workflows for daylight and artificial lighting design. These include (see [3:1, 3:2, 3:3, 3:4]):

- Limited standardization of lighting parameters: While BIM supports standardized object libraries, lighting-related data (e.g., daylight factor, illuminance levels, dynamic control settings) are not yet fully harmonized across different tools and platforms.

- Interoperability issues between BIM and BEM: Many energy simulation tools still require manual adjustments to import lighting data from BIM models, leading to data inconsistencies and additional workload.
- Lack of integration in the operational phase: While BIM is commonly used in design and construction, its role in post-occupancy lighting optimization and real-time control is still developing. The transition from BIM as a static planning tool to BIM as an interactive control platform remains an ongoing research topic.

3.1.3 Advances in BIM-based Lighting Simulations

BIM workflows for integrated daylight and artificial lighting blend model-export interfaces, parametric/generative design and multi-domain simulation loops to close design performance gaps. Research emphasizes early-stage parametric exploration, coupled static/dynamic simulations, and control-aware models to reduce artificial lighting loads while meeting visual comfort targets.

- **Model-to-simulation coupling** uses BIM as the authoring source and exports geometry and material properties to ray-tracing and energy engines for daylight and thermal analysis [3:5, 3:6].
- **Static-dynamic coupling** (iterative daylight/glare and dynamic simulations) has been proposed to address climate adaptability and glare control, producing measurable reductions in artificial lighting demand in case work [3:7].
- **Parametric and optimization loops** integrate visual programming and multi-objective algorithms (genetic algorithms, *RBFOpt*) to trade daylight autonomy versus energy use intensity during concept design [3:8, 3:9].
- **Control and IoT integration** is emerging: studies propose BIM-driven configuration of lighting controls and closed-loop operation using IoT, aiming to coordinate daylight harvesting and electric lighting [3:10, 3:11].

Traditional lighting design processes still often rely on loosely coupled or semi-integrated workflows using standalone simulation tools, which are not always fully integrated in BIM. This creates data exchange inefficiencies, requiring manual geometry imports, parameter adjustments, and result interpretation. To address this, new approaches focus on integrating lighting analysis tools directly within BIM environments, enabling real-time assessment and feedback loops.

3.1.4 Existing BIM-workflows from scientific literature

This section summarizes widely used BIM, daylighting and analysis platforms and highlights their typical roles and capabilities in an integrated workflow scheme. Table 1 highlights representative tools used in the literature and their principal function in BIM-lighting workflows.

TOOL OR PLUGIN	TYPICAL ROLE IN WORKFLOW	REPRESENTATIVE SUPPORT IN LITERATURE; WEB-LINKS
RELUXCAD / DIALUX	Model creation and calculation directly in Revit, presentation of results, export (one-way) to Relux Desktop. Both tools allow import of geometry data, partly with metadata, and re-import of results	https://relux.com/lighting-planning/bim-cad/revit https://www.dialux.com/en-GB/
RADIANCE / DIVA / HONEYBEE + LADYBUG	High-fidelity ray-tracing daylight simulation and environmental scripting (often via Rhino/Grasshopper)	Common path for detailed daylight and glare analysis and parametric loops [3:9, 3:12] https://divadocs.readthedocs.io/en/latest/ https://www.ladybug.tools/

CLIMATE STUDIO	Own Revit export file (*cse), import of geometry data in the CS Rhino plugin, no metadata	https://www.solemma.com/climatestudio
AFTABRAD	Radiance daylight calculation based on Revit geometry, material data sourced from Revit model	https://aftabsoft.net/aftab-rad.php
REVIT2RADIANCE / REVIT2MODELICA PROTOTYPES	Automated export of Revit BIM to Radiance or Modelica to run daylight/thermal sim directly	Demonstrated Revit → Radiance export and multi-domain simulation prototypes [3:6, 3:13]
REVIT + INSIGHT / SEFAIRA	BIM authoring with built-in/plug-in daylight and energy metrics for early design	Used in workflow comparisons and parametric studies [3:9, 3:12] https://support.sefaira.com/hc/en-us
HYPAR AND DOMAIN-SPECIFIC TOOLS	Performance analysis platforms used with Revit exports for coupled simulations	Applied in a BIM-driven static-dynamic daylighting workflow in a case study [3:7] https://hypar.io/
GAME ENGINES / UNREAL ENGINE	Real-time visualization and immersive evaluation; used for perceptual design and virtual testing	BIM → Unreal pipelines used for immersive lighting studies and real-time feedback [3:8, 3:14] https://www.unrealengine.com/
OPTIMIZATION LIBRARIES (RBFOPT, GA)	Search/optimize building form, WWR, and shading for sDA / EUI tradeoffs	Integrated into BIM parametric workflows for multi-objective optimization [3:8, 3:15]

Table 1: Representative tools used in the literature and their principal function in BIM-lighting workflows.

Even though several tools come up with specifically developed plug-ins, for a software-independent use of the described workflow, the openBIM approach via IFC is essential, enabling both geometric and alphanumeric data exchange between design and simulation tools. In following, several mentioned applications from previous table were evaluated for their suitability in daylight and artificial light simulation using a simple multi-zone building model as a test case - following practical insights could been made:

- **DIALux evo (https://www.dialux.com/en-GB/):**
  Among lighting tools, DIALux is one of the few that supports IFC-based BIM exchange. The import of geometric models works well, but the focus remains primarily on geometry. Although defining target values or product parameters could, in theory, be done via the PSet IFClamp, DIALux does not support this. Instead, DIALux collaborates with Relux on the GLDF format for luminaires, a proprietary standard by the two market leaders, deviating from the openBIM concept via IFC.

- **ReluxCAD for Revit (https://relux.com/lighting-planning/bim-cad/revit):**
  Relux offers a paid Revit plugin for direct luminaire specification, artificial light simulation, and result visualization within Revit. This represents a closed BIM solution, avoiding IFC's lack of parameter standardization while simplifying development by focusing solely on Revit. Users of other BIM tools such as Allplan or Archicad cannot use the plugin.

- **ElumTools (https://lightinganalysts.com/elumtools/):**
  Also implemented as a Revit plugin, ElumTools effectively supports lighting designers in quantifying and understanding room lighting conditions. It can calculate various photometric metrics (illuminance, luminance, etc.), using existing lighting instances or generating them within Revit. For daylighting, it can determine the daylight factor.

- **ClimateStudio (https://www.solemma.com/climatestudio):**
  A new Rhino plugin for integrated daylight, electric light, and energy simulations, ClimateStudio defines its own data format (*cse* – *ClimateStudio Export*). A dedicated Revit plugin exports models in this format, which can then be imported into Rhino. However, only geometric data are transferred—no lighting or thermal properties are included.

- **AftabRAD (https://aftabsoft.net/aftab-rad.php):**
  Developed as a Radiance-based plugin for Revit, AftabRAD performs daylight factor, annual daylight, and glare simulations directly within Revit. It generates necessary Bash scripts for running Radiance externally, while results are visualized back in Revit. Thus, no separate geometry export format is required.

- **Ladybug Tools (https://www.ladybug.tools/), Pollination (https://www.pollination.solutions/):**
  Under the name Pollination, Ladybug Tools now offers paid Rhino and Revit plugins in addition to its well-known Grasshopper components. These provide preconfigured workflows that streamline geometry transfer and correction between architectural and energy models. Although Ladybug Tools maintains an open-system philosophy, the IFC-based openBIM workflow as envisioned in BIM2BEM is no longer easily achievable within this framework.

Generally, the literature identifies recurring interoperability barriers and practical solutions to join BIM authoring, daylight engines and energy/control systems. Early work-built API translators; more recent studies add automation and scriptable pipelines.

Challenges

- **Geometry and semantic loss** when exporting from BIM to simulation engines; complex fenestration, glazing and shading details are often simplified in export routines [3:6, 3:12].

- **Inconsistent input parameter expectations** across tools (material definitions, sensor/grid setups, sky/weather formats), causing mismatches in reproduced results [3:12].

- **Limited modelling of controls and schedules** in standard BIM data, impeding accurate electric-lighting and control simulations [3:11].

Documented solutions and prototypes

- **API-based exporters** such as Revit2Radiance/Revit2Modelica automate translation of BIM geometry and attributes into Radiance/Modelica inputs to reduce manual data re-entry [3:6, 3:13].

- **Automation scripts and validation workflows** for building renovation assessments (BIM→BREEAM) demonstrate scripted extraction and metric calculation for large inventories [3:16].

- **Parameter homogenization and pre-processing** (e.g., standardized weather/sky inputs and material mapping) plus hybrid workflows (BIM → 3D CAD → simulation) reduce data loss in complex cases [3:12, 3:17].

Automated BIM pipelines improve repeatability and allow integration of parametric/optimization loops, but authors stress continued need for careful validation of exported inputs and results [3:6, 3:15, 3:12].

References that document prototypes, comparisons and automated workflows are provided in [3:6, 3:15, 3:12, 3:13, 3:17].

3.1.5 Advances in BIM-based Lighting Control Integration

3.1.5.1 The State of Research in Integrating Controls in a DT

The use of digital twins (DT) in the building sector stems from the need to holistically model complex systems and continuously improve them. Sensors merely provide the necessary operational data, which is integrated into a digital twin. While BIM primarily serves as an information basis for planning and documentation, the continuous feedback of operational and sensor data into the model creates a dynamic representation of the actual building [3:1]. The transformation from BIM to DT thus links the static planning model with a bidirectional data flow from building operations. Digital twins thus become a virtual representation of physical systems, enabling simulation, analysis, and optimization. In the building sector, they promise, among other things, lower operating costs, predictive analytics, improved decision-making, and optimized collaboration throughout the entire lifecycle. In particular, discrepancies between planning and actual operation can be identified, and actual building performance can be specifically improved [3:18].

A key benefit of this approach lies in the continuous commissioning and optimization of building systems. Operational data can be used to dynamically adapt control logic, for example, to actual usage patterns or changing environmental conditions [3:18]. DTs enhance lighting control strategies by adjusting artificial lighting based on real-time daylight availability, improving energy efficiency while maintaining user comfort. However, the literature reveals that the integration of lighting control strategies within BIM-based Digital Twins is still in its early stages. This leads to iterative improvements in building performance throughout the entire lifecycle while also allowing for greater consideration of user-dependent factors.

In practice, however, its adoption remains limited, primarily due to fragmented data and model landscapes, isolated domain-specific development processes, and a lack of standardized integration mechanisms. Furthermore, the manual configuration of interfaces, semantic mappings, and visualization layers becomes increasingly time-consuming as project complexity rises [3:1].

Even though the establishment of integrative control strategies in the BIM environment for daylight and artificial lighting systems is not yet well developed according to the existing literature, other related fields already show a significant amount of published research. One example is the field of fault detection for HVAC systems, which requires a broad system information level due to the system complexity, whereas BIM can provide a powerful environment as a single source of information. In addition, the field of fire protection comes up with plenty of research activities, whereas BIM can also build a suitable environment to localize and control fire- or smoke-detecting sensors in facility management. The following sections highlight the processes and concepts of relevant work to provide useful input for daylight and artificial lighting control applications.

3.1.5.2 Existing Approaches to Develop and Optimize Integrating Control Approaches

Existing research in control development and integration within the BIM environment predominantly focuses on HVAC systems, with limited attention given to integral daylight and artificial lighting. The limited development in this area is primarily attributed to the lack of standardization, the high complexity of lighting and building automation systems, and ongoing interoperability challenges between BIM, simulation tools, and control platforms [3:1, 3:2].

Despite these challenges, the urgency for solutions has increased in the face of issues such as summer overheating, elevated user comfort expectations, and the growing prominence of low-energy building concepts. While existing research articles outline strategies for incorporating controls within the BIM process, they predominantly pertain to HVAC and general building energy systems [3:1]. Findings from the literature review [3:1] emphasize the importance of extending these strategies to integral daylighting and artificial lighting controls, recognizing their applicability and potential for addressing contemporary challenges in construction and building performance.

Challenges and barriers in the practical implementation of integral controls for daylight and artificial lighting systems are manifold: (i) interoperability issues between BIM and software tools in the planning phase due to missing standardizations, (ii) shortcomings in data accuracy and consistency due to missing execution workflows and binding responsibilities between different trades and planners, and (iii) obstacles in accurately modelling as-build systems due to missing specification data as a consequence of insufficient BIM property sets, especially when it comes to daylighting systems [3:1, 3:18]. This leads to mistrust regarding the further use of transmitted data and, in turn, causes a lot of unnecessary pre-/post-processing work. It also hinders smooth communication via existing building management systems, especially between the existing proprietary control systems which are widely used in the market.

3.1.6 Future Research Directions and Outlook

The future of BIM-integrated lighting workflows lies in the further development of automated, standardized, and interoperable tools. Some promising directions include:

- Developing standardized parameter sets for lighting control within IFC (Industry Foundation Classes) models, improving interoperability with energy simulation software.
- Enhancing AI-driven predictive lighting control, where machine learning algorithms optimizes artificial lighting usage based on daylight availability, occupancy patterns, and energy demand.

- Expanding Digital Twin applications to enable continuous monitoring and adjustment of lighting conditions in response to real-time sensor data.
- Bridging the gap between BIM planning and operational control, ensuring that planned lighting strategies are effectively implemented and fine-tuned throughout a building's lifecycle.

As BIM methodologies continue to evolve, integrating daylight and artificial lighting workflows will become increasingly relevant for achieving holistic, energy-efficient building designs. This underscores the need for closer collaboration between lighting specialists, software developers, and standardization bodies to unlock the full potential of BIM-driven lighting optimization.

3.2 BIM2BEM-Flow: example process workflow for design-integrated energy- and daylight evaluation

The BIM2BEM-Flow project [3:19] aimed to bridge the gap between BIM and Building Energy Modeling (BEM) by developing a structured toolchain that facilitates seamless data exchange between Revit and simulation software. The need for this project came from the challenges faced in early-stage building performance optimization, where crucial design decisions impact energy efficiency but are often hindered by interoperability issues, lack of standardized parameters, lack of early-stage parameter values, and inefficient data management.

To facilitate the integration of BIM and BEM, the BIM2BEM-Flow toolchain was developed (Figure 1). This toolchain is designed to overcome interoperability challenges by standardizing project-specific parameter management, structuring workflows, and enabling automated data exchange between BIM tools and simulation software. It consists of three key components:

- The Parameter Database Application (YAPS) – A centralized system for managing and mapping project-specific parameters
- The Project Workflow Manager (PWM) – A coordination platform for defining exchange workflows (exchange scenarios) and responsibilities
- The Revit Workflow Manager (RWM) – A plugin that integrates workflow-specific parameters into BIM models and secures a tool- and workflow-specific validated IFC Export

Together, these tools streamline the BIM-to-BEM process by ensuring structured, automated, and validated data exchange, ultimately enhancing the accuracy and efficiency of energy simulations. By increasing consistency of data flows, trust in an integral planning process can be supported, which is also a key obstacle for BIM to BEM working processes.

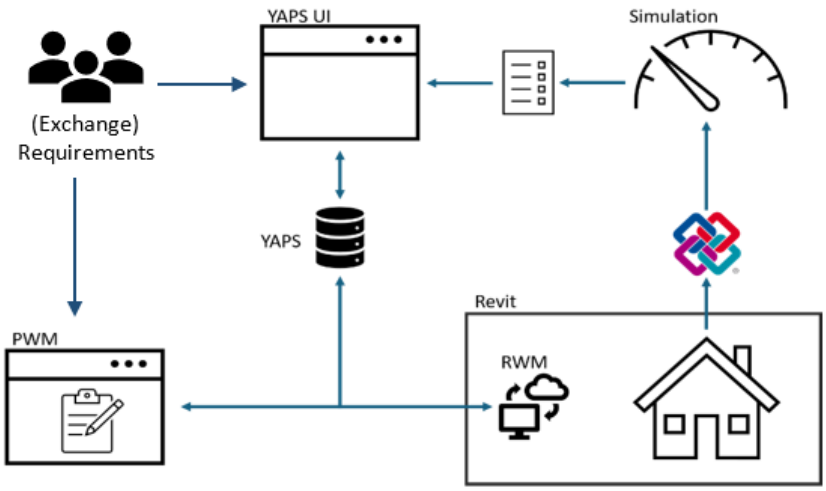


Figure 1: BIM2BEM-Flow workflow.

3.2.1 Parameter Database Application (YAPS) – Managing and Structuring Data

At the heart of the BIM2BEM-Flow toolchain is the YAPS (Yet Another Property Server), a web-based database application that serves as a central repository for company, tool- and/or project-specific parameters. One of the major challenges in BIM-integrated simulations is ensuring that all necessary parameters – such as thermal transmittance, daylighting metrics, or artificial lighting properties – are properly defined and consistently transferred across different tools.

The YAPS database provides a structured environment where users can store, manage, and map parameters to specific software applications. It allows for:

- Standardization of key properties, ensuring compatibility between BIM and BEM tools
- Definition of default values, enabling meaningful energy simulations even at early design stages
- Mapping capabilities, aligning parameter names and units across different tools

By acting as a central hub for parameter exchange, YAPS eliminates data inconsistencies and manual re-entry efforts, allowing project teams to work with pre-validated and simulation-ready data.

3.2.2 Project Workflow Manager (PWM) – Coordinating Exchange Requirements

While YAPS provides a foundation for standardized data management, the Project Workflow Manager (PWM) ensures that this information is properly structured and shared across different project stakeholders.

The PWM allows users to define specific BIM2BEM workflows, which outline:

- Which BIM tool and simulation tool are being used (e.g., Revit to DALEC, PHPP, or EnergyPlus);
- Who is responsible for handling and verifying parameters;
- Which project phase and use case scenario the workflow belongs to (e.g., daylight simulation, artificial lighting analysis, heating and cooling load estimation);
- Which defined libraries on the YAPS have to be used for this specific workflow.

By defining these workflows at the start of a project, PWM ensures clear responsibilities and prevents miscommunication in parameter exchange. This structured approach also minimizes errors by allowing users to retrieve only the parameters relevant to a specific workflow, reducing data clutter and ensuring that each simulation tool receives exactly the information it requires.

3.2.3 Revit Workflow Manager (RWM) – Seamless BIM Integration

To ensure that BIM models are properly enriched with simulation-ready parameters, the Revit Workflow Manager (RWM) was developed as a plugin for Autodesk Revit.

Once a workflow is defined in PWM, the RWM handling the PWM workflow packages to coordinate Information with the YAPS allows users to:

- Import the workflow-specific parameters into a BIM model
- Modify and validate parameter values directly within Revit
- Ensure correct mapping and formatting of parameters for simulation tools
- Export a validated IFC file, ensuring compatibility with external energy simulation software

One of the biggest challenges in BIM-to-BEM workflows is the correct structuring of data for export. The RWM automates this process by using predefined mapping rules stored in YAPS. These mapping rules ensure that

parameters such as U-values, solar heat gain coefficients, and lighting power densities are correctly formatted, named, and assigned within the IFC export file, making them immediately usable for energy simulations. Also, each YAPS library can have different definition of default-set libraries which can be used to pre-fill undefined parameter values in early design stages, to ensure early design performance optimization. Figure 2 shows an example for the mapping structure.

Moreover, the RWM includes built-in validation checks, warning users if critical parameters are missing or incorrectly assigned before export. This prevents common errors that would otherwise require extensive post-processing, saving valuable time and ensuring a smooth transition from BIM to simulation environments.

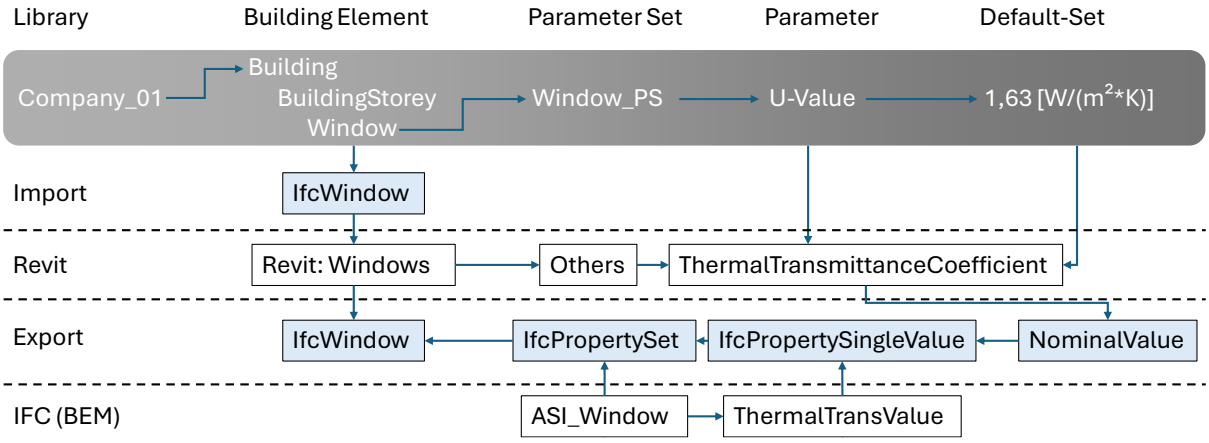


Figure 2: Example of mapping structure in BIM-to-BEM workflow.

3.2.4 Mapping and Simulation Data Exchange

One of the biggest challenges in BIM-integrated energy simulation workflows is ensuring that the right parameters are correctly transferred between BIM and BEM (Building Energy Modelling) tools. While BIM platforms like Autodesk Revit provide a rich environment for defining and managing building components, they are not inherently designed to facilitate energy simulations. Instead, dedicated BEM tools such as EnergyPlus, DALEC, PHPP, or IDA ICE require specific input formats, structured datasets, and well-defined parameters. The process of transforming a BIM model into a simulation-ready dataset involves parameter mapping, data structuring, and interoperability standardization – all of which present significant technical and methodological challenges. Miller et al. [3:4] present a standardized property framework and a three-step BIM-to-BEM toolchain that improves interoperability between BIM and building energy modelling, enabling more effective early-stage energy performance analysis through validated parameter mapping and integrated IFC-based workflows. The core findings are summarized here.

A fundamental issue in BIM-to-BEM workflows is that different software platforms utilize incompatible naming conventions, measurement units, and hierarchical data structures. For example, while Revit might store a thermal transmittance value as “ThermalTransmissionCoefficient”, another simulation tool may require the same property under a different name, such as “U-Value”. Similarly, solar heat gain coefficients, lighting power densities, and window properties must be translated accurately across platforms to ensure that energy models receive complete and meaningful input data. Without a structured approach to mapping and simulation data exchange, errors can occur, leading to inaccurate simulation results, inconsistencies, and time-consuming manual corrections. Ideally, all exchange parameters for all platforms would be standardized or described semantically in such a way that ontologies could be used. However, this is not currently the case – even though *buildingSMART* and other institutions are working on it – and is not foreseeable soon. Until then, a flexible mapping solution is the best approach.

To overcome these challenges, the BIM2BEM-Flow project has introduced a systematic mapping mechanism that aligns company-, project- and tool-specific parameters across BIM and BEM tools. This mechanism ensures that each BIM parameter is correctly translated into the expected format for energy simulations, eliminating data mismatches and enabling a more reliable and automated workflow. The mapping process follows a structured approach:

- Parameter Standardization and Centralized Management

- All exchange parameters are stored in a centralized parameter database (YAPS), ensuring uniform naming conventions and data consistency.
- Each parameter is mapped across different software tools, allowing users to automatically translate values into the required formats.
- Default values are assigned to parameters where necessary, providing meaningful input even at early design stages when detailed data may not yet be available.
- Automated Parameter Mapping and Data Transformation
- The Revit Workflow Manager (RWM) automatically pulls relevant parameters from the YAPS database and imports them into Revit models.
- When exporting the BIM model to IFC format, parameters are automatically mapped to their corresponding BEM equivalents, ensuring compatibility with external simulation tools.
- Data transformation is applied where necessary, converting units (e.g., W/m²K to BTU/hr·ft²·°F) and restructuring information to align with simulation tool requirements.
- Validation and Quality Assurance
- Before exporting a model, the RWM plugin performs a completeness check, ensuring that all required simulation parameters are present and correctly formatted.
- If missing or inconsistent values are detected, users receive real-time warnings and recommendations for corrective actions.
- This pre-export validation step reduces errors, minimizing the need for manual data adjustments in simulation tools.

Despite these automation efforts, interoperability challenges remain a key issue in BIM-to-BEM workflows. While IFC (Industry Foundation Classes) and *gbXML* serve as widely accepted open standards for building data exchange, they do not fully meet the complex requirements of energy simulations. The IFC schema, for instance, lacks depth in defining HVAC systems and building physics parameters, while *gbXML* struggles with geometric accuracy when handling curved or irregularly shaped elements. Moreover, many BEM tools do not natively support IFC imports, requiring additional conversion steps that can introduce errors and inconsistencies.

To address these interoperability issues, the BIM2BEM-Flow project leverages a combination of IFC and tool-specific mappings. The IFC-based approach ensures that building geometry and metadata are preserved, while the parameter mapping system translates simulation-critical alphanumerical properties into formats recognized by *Rhino-Grasshopper Honeybee* (*EnergyPlus*), *DALEC*, *PHPP* and other tools.

A crucial advantage of this structured mapping approach is that it enhances the reliability of simulation results by ensuring that only validated and correctly formatted data is used. Traditionally, architects and engineers have had to manually extract, clean, and input data into energy modelling tools, often resulting in errors, double work, inconsistencies, and a lack of traceability. By implementing a role-based (*YAPS*-Parameter Manager) workflow with clear data ownership, BIM2BEM-Flow ensures that responsibility for each parameter is explicitly assigned. This trustable data exchange mechanism helps bridge the gap between design intent and realized performance, ultimately reducing the performance gap observed between planned energy efficiency goals and actual building operation.

Moving forward, future enhancements in mapping and simulation data exchange may focus on AI-driven parameter matching, machine learning-based data validation, and tighter integration with cloud-based simulation platforms. Standardization efforts, such as *buildingSMART's* Information Delivery Specification (IDS), may also play a crucial role in improving openBIM-based interoperability, further streamlining BIM-to-BEM workflows. So far, only BIM tools have shown interest in integrating IFC standards according to *buildingSMART*; BEM tools are still lagging behind in this regard. In order to implement a future BIM2BEM process consistently, it is more important for BEM tool providers to improve their implementation of the IFC standard for import, especially at the level of alphanumeric information.

In summary, the BIM2BEM-Flow mapping system provides a structured, automated, and error-resistant approach to simulation data exchange. By centralizing parameter management, automating data transformation, and

ensuring robust validation mechanisms, this approach significantly reduces manual workload, improves accuracy, and enhances the efficiency of BIM-integrated energy modelling and increase trust in exchanged data. This innovative toolchain is a critical step toward fully realizing the potential of BIM-driven energy optimization, allowing for more informed decision-making and better-performing buildings in the long run.

3.2.5 A Fully Integrated Toolchain for BIM-Driven Energy Simulations

The proposed toolchain within the BIM2BEM-Flow project provides a novel approach in handling information and data among planning stages, planners and software tools. By combining *YAPS*, PWM, and RWM, the BIM2BEM-Flow toolchain creates a seamless, standardized, and automated approach to BIM-based energy simulations. *YAPS* ensures a structured data foundation, PWM facilitates workflow coordination and stakeholder responsibility, while RWM guarantees the correct application of parameters within the BIM model and their validated export for simulations.

This toolchain not only reduces errors and inefficiencies but also enhances collaboration between architects, engineers, and simulation experts, paving the way for more reliable and accurate BIM-integrated energy performance assessments.

3.2.6 Further developments to support an openBIM workflow with Revit and Rhino/Grasshopper

The tools and results of the BIM2BEM-Flow project have been used to support a new Revit2Rhino+GH workflow, developed withim the *AchieVE-ZEB* project (Achieving Zero Emission Building Stock with Viable Educational Programs; funded by the LIFE-2023-CET funding program; https://www.achieve-zeb.eu/). Based on Grasshopper *Honeybee* modules within Rhino, multiple *python* moduls have been developed to merge and reduce the amount and complexity of the *Honeybee* modules and also automate manual processes. The geometry is imported and renderd into Rhino via IFC, also the information about construction layers and materials, as also information about controlling schedules and HVAC seetings are imported from the IFC. Further information is prepared for publication in the manuscript: *Miller, J., et al. Revit2Rhino+GH: A new BIM2BEM workflow with Revit and Rhino+GH to optimize digital planning processes.*

3.3 State of research on BIM-workflows for LCA-analysis in context of lighting design

BIM integrated with Life Cycle Assessment (LCA) represents a transformative approach to sustainable building design, yet its application to lighting systems remains an emerging and fragmented field. This subchapter synthesizes current research on BIM-LCA workflows specifically for lighting design, revealing that while several methodological frameworks and software solutions exist, significant challenges persist in standardization, data availability, and practical implementation. The field is characterized by early-stage simplifications, parametric workflows, and IFC-based interoperability solutions, but lighting-specific modelling – particularly for controls, luminaires, and operational lifecycles – remains underdeveloped. Future research must prioritize standardized data exchange formats, validated product databases, and seamless integration of lighting simulation with LCA tools to enable comprehensive environmental assessment of lighting systems throughout the building lifecycle.

3.3.1 Overview of BIM-LCA Integration Approaches

In the literature, three principal methodological families for integrating LCA into BIM workflows, each with distinct characteristics regarding timing, data requirements, and automation level, can be identified independently from the lighting design context.

3.3.1.1 Early-Stage Simplified LCA

Early simplified LCA approaches use limited geometric information and parametric rules to provide rapid environmental feedback during conceptual design phases [3:20]. These methods prioritize speed and accessibility over precision, enabling designers to compare alternatives before detailed specifications are finalized. For

lighting, this might involve estimating impacts based on floor area, lighting power density targets, and generic luminaire categories rather than specific product selections.

The rationale for early-stage simplification is compelling: design decisions made during initial phases have the greatest influence on lifecycle environmental performance, yet detailed LCA is often too time-consuming and data-intensive to inform these critical choices [3:21]. However, the accuracy-speed trade-off remains a subject of ongoing research, with questions about which simplifications are acceptable for different decision contexts.

3.3.1.2 Detailed Semi-Automatic Workflows

Detailed workflows extract comprehensive quantities from fully developed BIM models and refine inventories in spreadsheets or dedicated LCA software for complete assessments later in the design process [3:22]. This approach leverages BIM's ability to automatically generate bills of quantities (BOQ) while preserving flexibility for manual adjustment and dataset matching.

For lighting systems, detailed workflows typically involve:

1. Modeling luminaires as parametric BIM families with embedded metadata;
2. Exporting quantity takeoffs and material specifications;
3. Mapping BIM objects to Life Cycle Inventory (LCI) databases;
4. Performing impact calculations in specialized LCA software;
5. Iterating design based on results.

While more accurate than simplified approaches, detailed workflows face challenges in maintaining consistency between BIM models and LCA databases, particularly when design changes occur [3:22].

An integral approach supports the proactive identification and mitigation of environmental impacts before key design decisions become fixed. Various integrated eco-design methodologies have emerged to facilitate this process. For instance, concurrent LCA and design approaches employ rapid screening tools such as *One Click LCA* or *Sustainable Minds* during the conceptual phase, enabling designers to make informed choices regarding materials, geometries, and configurations.

3.3.1.3 IFC-Based Open Interoperability Frameworks

IFC-based approaches aim to enable continuous LCA across project phases by adding lifecycle elements and exchange schemas to standardized BIM data formats [3:23].

IFC-based frameworks offer several theoretical advantages:

- **Vendor neutrality**: Reduced dependence on proprietary software ecosystems
- **Phase continuity**: Consistent data structures from design through operation
- **Collaborative workflows**: Multiple stakeholders can access and update lifecycle data
- **Standardization**: Common semantics reduce mapping errors

However, current IFC specifications lack comprehensive coverage of lighting-specific attributes, particularly for control systems, operational profiles, and product-level environmental data [3:23, 3:24].

BIM opens up the possibility of directly linking geometric, material-related, and performance-relevant information with LCA calculations. Studies show that combining BIM and LCA can lead to a significant increase in transparency, comparability, and the provision of decision-making bases for sustainable planning processes.

3.3.2 Lighting-Specific Integration Considerations

While the methodological families described above apply generally to building systems, lighting presents unique integration challenges and opportunities.

3.3.2.1 Luminaire Modelling and Product Data

Lighting LCA requires detailed information about luminaire construction (housing materials, LED modules, drivers, optics), manufacturing processes, and end-of-life considerations. Several studies have proposed approaches for embedding this data in BIM:

- **Parametric families**: Revit families with custom parameters for material composition, efficacy, rated life, and EPDs [25]
- **Product libraries**: Linked databases containing manufacturer-specific LCI data that can be queried based on BIM object properties [3:26]
- **Simplified proxies**: Generic luminaire categories (e.g., LED troffer, LED downlight) mapped to representative LCI datasets when specific product data is unavailable [3:20]

The challenge lies in maintaining current, comprehensive product databases. Manufacturer EPDs for luminaires remain relatively uncommon compared to structural materials, and generic datasets may not adequately represent the diversity of lighting technologies and their environmental profiles [3:26].

3.3.2.2 Control Systems and Operational Profiles

Lighting controls significantly influence operational energy consumption and thus lifecycle environmental impacts, yet BIM tools traditionally lack robust frameworks for modelling control strategies [3:27]. Recent research has begun addressing this gap:

A study by Hammes et al. developed concepts for BIM-based configuration and parameterization of lighting controls derived from literature and market research [3:27]. Their work identified key parameters that should be captured in BIM to enable accurate operational modelling:

- Control zones and groupings
- Sensor types and placement
- Dimming strategies and schedules
- Daylight harvesting algorithms
- Occupancy detection parameters

Integrating these control parameters with LCA requires coupling BIM with lighting simulation tools (e.g., *Radiance*, *DIALux*, *Relux*) to generate realistic operational profiles, which can then inform LCI calculations [3:20, 3:28]. However, standardized workflows for this integration remain underdeveloped.

3.3.2.3 Combined Embodied and Operational Assessment

Comprehensive lighting LCA must account for both embodied impacts (manufacturing, transport, installation, disposal) and operational impacts (energy consumption over service life). Research suggests that operational impacts typically dominate for many conventional lighting systems, but the balance can shift with LED technology, longer service lives, and advanced controls [3:20].

Recommended practice combines:

1. **Product-level LCI** for luminaires and control components (embodied impacts)
2. **Building energy simulation** coupled with lighting simulation (operational impacts)
3. **Maintenance and replacement modelling** based on rated life and failure rates
4. **End-of-life scenarios** including recycling potential for LED components

The challenge is that many BIM-LCA tools are optimized for static material quantities rather than dynamic operational modelling, requiring workarounds or custom scripting to incorporate lighting energy use [3:28].

3.4 Overview on existing lighting design tools with BIM & LCA integration

Recent literature highlights a paradigm shift toward integrating life cycle assessment (LCA) into the early stages of product design, rather than applying it as a post-hoc evaluation tool. Integrating LCA into these initial design phases offers several advantages, including the early identification of environmental hotspots, more cost-effective design modifications, improved alignment between sustainability goals and technical performance, and a reduced need for later redesign iterations. As a result, early-stage LCA integration is increasingly recognized as a key enabler of sustainable product innovation. Within Subtask A of IEA SHC Task 70 / EBC Annex 90, in addition to a survey on the country-specific situation regarding LCA, an extensive literature review was carried out [3:29]. The results relevant to BIM & LCA are presented here.

The relevant categories of the analysed papers (artificial lighting, daylight, combined lighting systems, and controls) of the literature review [3:29] are broken down in Figure 3 using a Sankey diagram according to the LCA tools used and their databases. The line thickness represents the frequency of the categories, tools, and databases in the articles examined. It can be seen that *SimaPro* is widely used in LCA studies related to both lighting and building systems, but it is not specifically tailored to daylight or lighting simulation workflows. *openLCA* is a general-purpose LCA tool that is also used in studies related to artificial lighting applications. The high proportion of studies without specific software information is striking, suggesting the use of individual tools or simplified methods and a lack of transparency. Studies using *SimaPro* often use the *Ecoinvent* database. *LCA Experts* is commonly used in combination with the *GaBi* database in industrial LCA applications.

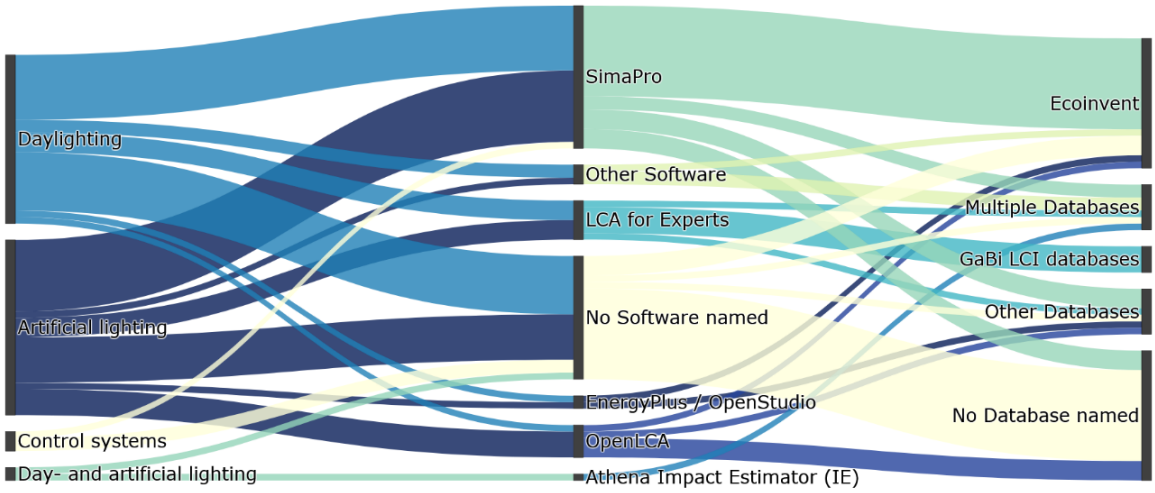


Figure 3: Sankey diagram showing the relation between categories (daylighting, artificial lighting, controls), LCA tools and databases as found in the literature.

3.4.1 BIM Authoring and Parametric Tools

3.4.1.1 Dedicated LCA Tools

Results of the bibliometric analysis show that the specialized software tools used for conducting LCA analysis in the field of artificial lighting are *SimaPro*, *LCA for Experts* (former: *Gabi*) and *openLCA* (Figure 4). While *SimaPro* and *LCA for Experts* offer solutions with extensive built-in databases and robust impact assessment methods, *openLCA* provides an open-source database with more flexibility for customized solutions and evaluations. Transient simulation tools (e.g., *EnergyPlus*, …) are widely used to calculate the energy consumption during the operational phase of lighting system in context to the overall building energy demand and are also commonly used within LCA studies for lighting systems, as the operational phase is still the most impacting phase for lighting applications [3:35]. On building-integrated system evaluation, also lighting design software (e.g., DIALux) are used for system sizing and energy calculations, which results can then also be imported into appropriate LCA tools.

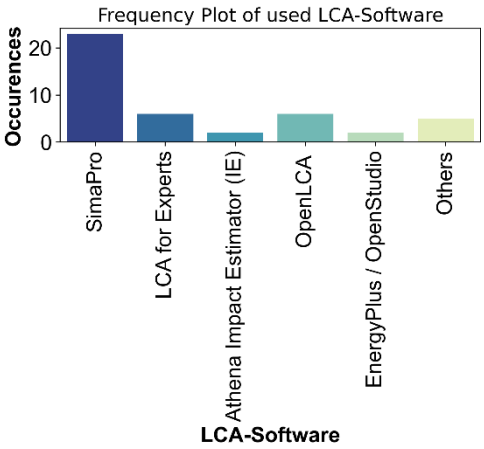


Figure 4: LCA software used in the field of artificial lighting.

By looking at the different software tools applied in individual studies in the lighting field, *SimaPro* is among the most frequently used LCA tools in the reviewed literature, particularly for LED luminaires and lighting systems, which integrates the *Ecoinvent* database for life cycle inventory data and applies to endpoint life cycle impact assessments, including human health impacts and emissions throughout the life cycle. BIM-integrated frameworks are emerging and incorporate LCA-tools like *OneClick LCA* and *Tally* from GreenBuildingStudio to evaluate environmental impacts of building materials and systems, including lighting [3:31, 3:32].

Following strengthens from some of the mostly used software tools can be mentioned:

- **SimaPro:** Comprehensive LCA tool with extensive databases (ecoinvent, GaBi) and impact assessment methods. Used in semi-automated workflows where BIM exports are refined in spreadsheets before import [3:5]. Offers detailed modeling capabilities but requires significant LCA expertise.
- **GaBi:** Similar to SimaPro in functionality, with strong industry adoption. Less commonly reported in BIM-LCA research but used in manufacturer EPD development.
- **OneClick LCA:** Cloud-based platform designed specifically for building LCA with direct BIM integration. Offers plugins for Revit and IFC import, with built-in construction material databases. Increasingly adopted in practice but with less academic validation than SimaPro [3:30].
- **Athena Impact Estimator:** North American focus with region-specific construction databases. Free access supports adoption but limited geographic applicability.

3.4.1.2 BIM-Integrated LCA Plugins

A key requirement in construction practice is the development of tools and workflows that enable the early integration of LCA, LCC, and their combined consideration in the design process. Methods such as multiple linear regression analyses or parametric approaches allow design variables and their areas of influence to be examined before comprehensive simulations or cost-benefit analyses are carried out [3:25]. The combination of BIM-supported tools such as Tally or OpenLCA with established databases such as Ecoinvent or GaBi is particularly relevant for estimating the embodied environmental impacts of materials and components early on in the planning phases [3:24, 3:25].

Several plugins have been developed to embed LCA capabilities directly in BIM environments:

- **Tally (KT Innovations):** Revit plugin providing real-time LCA feedback using material takeoffs and GaBi database. Supports comparative analysis but with limited transparency in calculation methods. Lighting-specific capabilities are minimal, treating luminaires as generic manufactured products [30].
- **OneClick LCA Revit Plugin:** Direct integration enabling continuous LCA updates as design evolves. Includes some lighting product data but coverage varies by region and manufacturer participation [30].
- **IMPACT (Circular Ecology):** UK-focused tool with emphasis on embodied carbon. Limited lighting-specific functionality.

A common limitation across plugins is the treatment of lighting as a secondary system, with less detailed modelling than structural and envelope components [3:26, 3:30].

3.4.1.3 Industry Foundation Classes

IFC serves as the primary open standard for BIM data exchange, maintained by *buildingSMART* International. Relevant IFC entities for lighting LCA include:

- IfcLightFixture: Geometric and placement information for luminaires
- IfcMaterial: Material definitions used in the model
- IfcPropertySet: User-defined property sets, which can include environmental data
- IfcClassificationReference: Links to product databases and EPDs

However, current IFC schemas lack standardized lifecycle attributes for lighting systems. The BIM2LCA project proposed extensions including [3:23]:

- Lifecycle phase tags (A1-A5: production; B1-B7: use; C1-C4: end-of-life; D: beyond lifecycle)
- Environmental indicator properties (GWP, PED, etc.)
- Service life and replacement intervals
- Control system parameters and operational profiles

These extensions require formalization through buildingSMART's IDM and MVD processes to achieve widespread adoption [3:23, 3:24].

3.4.2 Applied environmental databases

Ecoinvent is the most frequently used database across studies, providing robust life cycle inventory data for lighting systems, including LED luminaires and building materials (see Figure 5). Also, the *GaBi* LCI database has been evaluated as widely used, applied in endpoint life cycle impact assessments and particularly for emissions and human health impacts. Other databases, like custom inventory databases are very specific and rely on tailored inventory data specific to manufacturing processes, especially for modular luminaires and small-scale enterprises, where else several works also accessed multiple databases in their work.

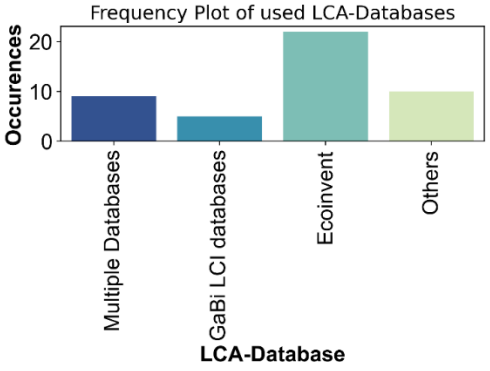


Figure 5: Databases used in LCA for lighting systems.

Most EU countries have developed databases for LCA analysis, but also the United States as well the European Union provide free databases. Although some institutions and organizations can conduct life cycle assessments of specific products, and issue professional EPDs (Environmental Product Declaration), it is a complicated task for lighting products due to the numerous and delicate components. Many databases only contain basic environmental indicators of construction materials and components and only some databases like in China, Denmark, Finland, France, Germany, Ireland, Italy, Norway, Poland, Sweden so far contain luminaires-specific values. Some EU countries provide already databases containing EPDs for various building components and products. The databases of Denmark, Germany, Ireland, Italy, Norway and the European Union are more detailed and

comprehensive than others, including the materials, weight, life, power, and carbon emissions at multiple important life cycle stages, and indicate the criteria, such as EN 15804:2012 + A2:2019.

The majority of LCA studies in the screened literature rely on standardized databases like *Ecoinvent* to guarantee consistent and harmonized datasets and ensure methodological reliability. In contrast, custom inventory data offers flexibility by accurately modelling unique manufacturing processes or regional conditions, benefiting small enterprises and emerging technologies. However, custom data often lacks standardization and makes comparability across studies challenging. While meanwhile, *Ecoinvent* has improved regionalized datasets, achieving similar accuracy with custom data requires significant effort and expertise [3:33, 3:34].

3.5 BIM2Control and Control2BIM: example workflow for daylighting and artificial lighting systems

In its current form, BIM is only of limited use as a starting point for digital twins because it primarily represents static design and construction data. There is a lack of native capabilities for integrating operational and sensor data in real time, for bidirectional coupling with physical hardware, and for modelling runtime aspects such as control topologies and logic. This gap prevents seamless synchronization with building automation and complicates real-time processing, analysis, and feedback of control signals. What is needed are extensible and standardized workflows that supplement BIM semantics with operational structures and runtime models, systematically support integration with building services, and largely automate configurations. BIM can serve as the common collaborative foundation, while targeted extensions bridge the gap to operations, thereby enabling efficiency, comfort, and adaptability throughout the lifecycle.

The research project TwinLight [3:36] addresses this gap for natural and artificial lighting by developing a BIM-based framework with data-oriented middleware. The goal is a transparent, collaborative workflow that automatically derives executable configurations from design models, enables interoperability between heterogeneous protocols, and establishes a reliable link between the virtual and physical twins. To this end, a domain-specific language (DSL) along with a methodology and a Revit-based toolchain were created, which formally maps sensors, actuators, and control hardware, along with their parameters, identifiers, and connection logic, within the building model. The DSL is specified as a metamodel in Eclipse Ecore and visually implemented in Revit via families. A plugin automatically generates topology views at multiple levels of abstraction and checks the semantic correctness of the modelling. Data exchange between disciplines uses IFC as an open exchange format, allowing models from Revit to be exported to a central BIM repository and fed back from there into planning, building physics, and operations. From the enriched model, wiring and topology plans as well as executable artifacts are generated, which, as JSON and YAML configurations, contain the defined device classes, parameters, identifiers, topic namespaces, and mappings of commands to endpoints. These artifacts are automatically deployed to target hardware, creating a seamless chain from planning through to commissioning (more details in [3:37, 3:38, 3:18]).

The middleware architecture connects the BIM model with ongoing operations and transforms planning information into reliable data and control paths. It receives sensor data via MQTT, stores measurement series in a time-series database, and distributes events with low latency to analysis and visualization systems. A data processor converts all inputs into a consistent internal format based on a formal data model using JSON Schema, which describes the types, structures, and meanings of data and commands in a machine-readable way, thereby bridging device and protocol boundaries. The architecture separates queries and commands into a read path for evaluations and a write path for controls, which increases stability and responsiveness under load. For external systems, the middleware provides API endpoints, typically as REST for queries and as WebSockets or MQTT topics for events and status updates. The visualization layer utilizes these interfaces, synchronizes the current system state with the virtual scene, and enables interaction and testing prior to implementation. Role-based access control safeguards the bidirectional data flows. The configuration of these communication flows is generated directly from the BIM model, ensuring that topic structures, device identities, and rights management are consistently derived from the modelled topologies. When changes are made to the building model, the JSON and YAML artifacts can be regenerated and imported into the middleware, keeping digital twins and physical installations continuously synchronized (more details in [3:37, 3:38, 3:18]).

Through the continuous integration of operational data, the static BIM model evolves into a DT that enables simulation, predictive analytics, and ongoing optimization of control systems. Discrepancies between design and

actual use become apparent, and the control logic can be gradually adapted to real-world patterns [3:18]. Integrated visualization within an interactive 3D environment supports monitoring, diagnostics, and the simulation of changes prior to implementation. Overall, this creates an integrated, data-driven process that combines precise control mapping in BIM with the development of robust DT and a high-performance system architecture, thereby increasing efficiency, transparency, and collaboration in building operations.

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4 Data Specification

By David Geisler-Moroder

To ensure the correct mapping and transfer of data between the trades involved throughout the BIM planning process, the terms of the properties are standardized internationally. This ensures a seamless transfer between the individual steps in workflows as described in Section 3, regardless of the software used.

For lighting systems (including electric lighting devices and lighting controls) these properties are defined by the International Organization for Standardization (ISO) in the Technical Specification ISO/TS 7127:2023 [4:1].

The definitions contained therein include properties from various disciplines involved in the process, e.g., photometric properties, electrical properties, and mechanical or mounting properties, to name a few. The relevant properties can then be defined or accessed directly from the various modelling, analysis, evaluation or simulation environments for mapping the systems correctly in their respective environments.

In addition to the standard for lighting systems, similar activities have been started for daylighting and shading systems. Within the research project BIM2IndiLight [4:2], the University of Innsbruck, together with Bartenbach, HELLA and ATP, drew up a comprehensive list of the key parameters for such fenestration systems. Building on the preliminary work in the BIM2IndiLight project, activities are currently (as of mid-2025) underway at ISO level to define properties for daylight louver systems (ISO/PWI TS 23775 [4:3]).

4.1 Parameter specification in the BIM2Indlight project

By Josef Miller

In their paper *"Enhancing Interoperability Between Building Information Modeling and Building Energy Modeling: Alphanumerical Information Exchange for Energy Optimization in Early Design Stages"* [4:4], Miller et al. describe the results of the BIM2BEM-Flow project [4:5], which built upon the preliminary work conducted in the BIM2IndiLight project [4:6].

The BIM2IndiLight project focused on the development of an application designed to enrich building models with additional information in the form of component-level and project-level parameters within a Revit model. This application was implemented as a Revit plugin and served as the conceptual and technical foundation for the BIM2BEM-Flow project. Building on this foundation, several tools were developed within BIM2BEM-Flow: a database with a web-based interface for creating and managing alphanumerical information and defining mapping rules to ensure consistent data exchange between BIM authoring tools and simulation environments, a project management platform that assigns the defined parameter libraries from the database to specific workflows while also regulating responsibilities among project stakeholders, and a Revit plugin that integrates and coordinates the information from both the database and the project management platform within the Revit environment, thereby ensuring a validated and structured IFC export.

A second major component of the BIM2IndiLight project involved identifying and defining the required exchange parameters for daylighting, artificial lighting, as well as sensor and control systems. To achieve this, domain experts analysed guidelines, manufacturer datasets, standards, and other technical sources to establish a consensus on the necessary parameters. As a result of this process, 428 parameters were defined. When comparing these parameters to the IFC 2x3 standard, the analysis revealed that 23% of the artificial lighting parameters, 10% of the daylight parameters, and only 2% of the sensor and control parameters had corresponding definitions within the IFC schema. Another important finding was that only 46% of the daylight parameters and 72% of the sensor and control parameters were explicitly defined in existing standards and guidelines.

Within the BIM2BEM-Flow project, the coverage of these 428 parameters was re-evaluated against the more recent IFC 4.3 standard. During this process, certain duplicate entries were removed due to the differentiation between multiple shading system types. Consequently, 385 parameters remained for the final evaluation. The results show that 40% of these parameters are not defined in the IFC 4.3 schema, while 44% can be clearly assigned to existing IFC properties. Furthermore, 11% of the parameters could theoretically be mapped to IFC, but only through complex and deeply nested structures, making their implementation impractical in early design

stages. An additional 6% are theoretically assignable, yet the level of ambiguity within the IFC schema introduces too much interpretative flexibility to allow a reliable and unambiguous mapping.

In conclusion, standardization remains a fundamental prerequisite for reliable information exchange between BIM and BEM systems. The BIM2IndiLight project demonstrated that the definition and validation of more than 400 standardized parameters can provide a robust basis for structuring and mapping building information. Standardized parameters are particularly valuable in the context of defining Exchange Information Requirements (EIR), Exchange Requirements (ER), and Information Delivery Manual (IDM), as they establish a consistent framework for organizing and assigning information. They also facilitate clear communication among project stakeholders and reduce errors during the transfer of information between different software platforms, provided that all participating tools and stakeholders adhere to the same standards.

However, standardized parameters alone are not sufficient. Many BEM applications still lack robust support for importing alphanumerical information. In addition, the rapid evolution of design requirements and the nearly unlimited range of possible parameters make manual parameter maintenance both time-consuming and prone to error. Cross-border projects further complicate this issue, as they often encounter conflicting national standards. These challenges highlight the need for a more dynamic and adaptable approach to parameter management. Such an approach should enable flexible parameter libraries and incorporate standardized default-value libraries to support efficient and practical implementation in real-world workflows.

4.2 Parameter specification in international standards

By David Geisler-Moroder

To enable consistent data representation and mapping in software, a comprehensive definition of the individual parameters that describe a lighting system or a daylighting / shading system is required. At the international level, efforts are underway to standardize this for both, lighting systems (luminaries and sensors) as well as daylight louver systems.

4.2.1 BIM Properties for Lighting Systems

in the German-language book “BIM and Lighting” [7], Robert Heinze extensively describes relevant standard touching the field of BIM and lighting. He is also the main author of the international standard ISO/TS 7127 “Light and lighting – Building information modelling properties for lighting – Lighting systems” [4:1], which was first published in 2023. The scope of this standard is defined as:

> *“This technical specification identifies and clarifies lighting properties for digital building design and maintenance.*
>
> *This document provides all the needed properties to design and to describe lighting systems. These properties are intended to be used for mapping between data providers and requesters. The mapping of the identifiers enables the exchange of luminaire and sensing device data within different databases.*
>
> *The unambiguous mapping and description of properties improves the data quality, reduces misinterpretations and the processing time in digital environments. Therefore, the properties listed in this document establish the essential description of lighting systems in BIM systems and databases.*
>
> *The listed properties in this document are used to structure the product data sheet which is complemented with real product information.”* (cited from [4:1])

The standard defines properties for lighting systems to comprehensively describe devices such as luminaires or sensors and to enable understanding and exchange between the various parties involved in the BIM workflow (data providers and users). In nine tables, the following properties are specified:

- Mechanical properties
- Electrical properties
- Emergency lighting properties
- Photometric properties
- Sensing device properties
- Mounting & Accessory properties

- Marketing properties
- Operations & Maintenance properties
- Environmental properties

For each property, the following attributes are defined or described how to be set, respectively:

- GUID (“Globally unique identifier”)
- ID
- Name
- Description
- Symbol
- Format, Unit
- Value set
- Examples

The standardized parameter sets for lighting systems enable all providers of software, databases, and data (lighting manufacturers) to use uniform descriptions that are understood worldwide and can be applied and implemented exactly as intended

4.2.2 BIM Properties for Daylight Louver Systems

In parallel with the specification of BIM parameters for lighting systems in ISO/TS 7127 [4:1], it is also necessary to have such data available for daylighting and shading systems. A group of experts is taking the first steps in this direction; as of April 2026, they are drafting a “Working Document” ISO/WD TS 23775: Light and lighting – Building information modelling properties for lighting – Daylight louver systems [4:3]. The starting point for compiling the BIM parameter specification is the list of parameters that was created in the BIM2IndiLight project (see Section 4.1, [4:6]).

The scope of this new standard is defined as:

> *“This document identifies and clarifies daylight louver systems properties for digital building design and maintenance. This document provides all the needed properties to design and to describe daylight louver systems. These properties are intended to be used as mapping properties for property providers and requesters. The mapping of the identifiers enables the exchange of daylight louver systems data within different databases. The unambiguous mapping and description of properties improves the data quality, reduces misinterpretations and the processing time in digital environments. Therefore, the properties listed in this document establishes the essential description of daylight louver systems in BIM systems and databases. The listed properties in this document are used to structure the product data sheet which is complemented with real product information.”* (cited from [4:3])

The target date for publication of the international standard ISO/TS 23775 is end of 2027.

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5 Databases

By Christoph Maurer

This section first describes the challenges which many architects, designers and engineers face regarding BIM data. It then discusses the challenges of current product databases and presents solutions to use product data in BIM workflows.

5.1 Challenges regarding BIM data

When BIM is used in a construction project by few stakeholders for a small number of tasks, it often happens that files with BIM data are being exchanged. Obviously, this involves the risk of confusion between several files and the features which have been implemented in them.

When BIM is important in a construction project, it is recommended to store the BIM data in a BIM server. The BIM server uses a database to manage the data. The changes of the Building Information Model must be documented by the server so that each change can later be understood and removed if necessary. In OpenBIM, IFC are usually used to exchange the BIM data and BIM Collaboration Format (BCF) are used to describe the changes of the Building Information Model.

BIM data often needs so much storage that it takes hours to load it into a software. BIM data is therefore often separated into domains such as structural analysis, technical building plant, facade, … The domain models are then being combined e.g., once a week to search for possible conflicts between the domain models. Nevertheless, the storage size of the domain models needs to be reduced as much as possible to enable fast work progress. When we look at the geometry of a single lamp, we see that such a CAD file may need several MB of storage. Considering the amount of building components in domain model, it is important to reduce the size of product data. At the same time, the Building Information Model should contain all data which is needed by the stakeholders, for example by a lighting designer.

5.2 Challenges for Product Databases

There are several product databases to date. Component manufacturers and their associations have their internal product databases. They provide some product data on their websites. There are also websites which offer “Building Information Models” from many manufacturers. They typically include the geometry, categorization of the component and free text. They usually do not include detailed product data which is needed to plan integrated lighting solutions.

Planning software typically includes some product data. In many cases. architects, designers and engineers need to search manually for product data which fits to the calculation which they need to perform with their planning software. This needs much time and effort but is also error-prone. For designers, it would be best if they could choose a luminaire or shading in BIM once and could then access geometric and non-geometric product data in several levels of detail whenever it is needed in the process of the building project.

Some applications for building performance simulation do not yet offer the level of detail which is required by a planner. Product database can for example not include all possible combinations of glazing and shading.

5.3 Solutions for Product Databases and BIM Databases

The product data network buildingenvelopedata.org has been established to overcome the challenges for product databases. The product data network allows planning software to access the product data servers directly via an Application Programming Interface (API). The planning software can therefore make it easy for the architect, designer or engineer, because they do not need to understand anymore the details of the calculation, of the required quality of the data and the required format of the data. It only needs to be implemented once. The planning can then be faster because of the automation and many possible sources of errors are excluded. The automation allows comparisons between variants compared to the manual search and usage of product data.

The product data network does not yet contain luminaires and only limited number of shading components. However, it can easily be extended to cover geometric and non-geometric product data in several levels of detail.

With regard to the size of the BIM project, we recommend to limit the geometry of the components in the Building Information Model to the minimum, for example a bounding box. We recommend to add fields to the BIM components: The URL of an API which offers detailed product data, the unique identifier of the component, a query for the detailed product data and the URL of the API specification. The last two fields are optional, the first to fields are required. The additional data can for example include optical, calorimetric, geometric, photovoltaic, hygrothermal and life-cycle data.

The solution to the large number of possible combinations of glazing and shading are “methods as a service”. This means that the information about several components can be sent to an application programming interface which then performs the calculation of the combination and returns the results. In the overview https://www.buildingenvelopedata.org/methods, methods as a service have the URL of their application programming interface in the column “calculation”. Software companies can implement the methods as a service into their building performance simulation or they can implement it themselves.

When the concept is fully implemented by software companies, architects, designers and engineers can choose a component once and connect the relevant BIM data with their planning software. Then, the planning software can automatically download the required product data and perform the calculations. This makes the continuous workflow for integrated lighting solutions faster, easier and better.

6 Discussion

6.1 Lighting in the context of BIM & BEM

By David Geisler-Moroder, Sascha Hammes, Josef Miller

Effective BIM-to-BEM workflows depend on structured, validated data exchange and clear role definitions. The example implementation in the BIM2BEM-Flow toolchain combines a parameter server for centralized parameter management, and workflow managers for parameter coordination and Revit-side integration [6:1]. This demonstrates how standardized mapping, default values, and pre-export validation can reduce errors and build trust across disciplines. By aligning tool- and project-specific parameters and automating IFC exports, the approach addresses persistent naming, unit, and schema mismatches that otherwise degrade simulation reliability and demand costly manual fixes.

Yet, challenges remain. Interoperability gaps across BIM, BEM, and control platforms persist, with limited standardization of lighting parameters and incomplete support for alphanumeric data in open standards, slowing the integration of daylight and artificial lighting controls into mainstream practice. Even with automated mapping and unit conversion, many BEM tools lack robust IFC imports in total or only support geometrical information, necessitating tool-specific workarounds that risk error propagation. Moreover, while the urgency for integrated controls grows (e.g., visual and thermal user comfort), execution workflows and responsibilities across trades are still inconsistently defined, undermining data fidelity from design to operation. Approaches to transfer integral controls directly from the BIM model and the planning phase into operation as part of an automated commissioning exist and have been tested [6:2].

Linking BIM with BEM for the lighting trade brings advantages on many levels. For example, simulations and evaluations can be carried out in each planning phase based on the latest planning status. This allows deviations from the predicted performance to be detected at any time and performance gaps to be prevented after implementation [6:3].

6.2 Lighting in the context of BIM & Control

By Sascha Hammes, David Geisler-Moroder

BIM and Building Automation and Control Systems (BACS) should be understood as complementary components of a unified information ecosystem. BACS function as central information hubs that capture operational states and sensor data, which enables BIM to evolve from a static model to a continuously updated representation of the built asset. This feedback loop supports early deviation detection, optimization of control strategies, and data driven FM decision making, and is instrumental for the transition from BIM to DT [6:2].

Despite clear potential, integration remains constrained by heterogeneous protocols, proprietary software, and missing standardized interfaces between operational data models and BIM schemas such as IFC. Semantic gaps persist because BIM commonly models geometry and product semantics but not control logic and live operational data [6:4, 6:5, 6:6]. Ontology-based mappings and flexible middleware, including domain specific modelling languages, can provide bidirectional interoperability and hardware independent control representations [6:7]. IoT networks extend this data foundation and should be incorporated into the model.

Organizational barriers are decisive. Divergent responsibilities and fragmented trades reduce transparency and limit functionality, leaving efficiency and comfort potential unused. Liability concerns and risk-oriented routines frequently lead to intentional isolation of BACS despite available secure solutions. Governance, clear roles, data ownership, and incentives are necessary for adoption, alongside integrating operational objectives into planning [6:8]. Sustainable implementation requires standardized interfaces, ontology-based exchange, and institutional adjustments that formalize data management and system coordination across planning, operations, and IT.

6.3 Lighting in the context of BIM & LCA

By Sascha Hammes, David Geisler-Moroder

The application of LCA in lighting promises evidence-based decisions for sustainable products and planning. A wide range of tools, methods, and standards are available for the life cycle assessment of lighting. However, there is often a lack of transparency regarding the methods used, particularly with respect to system boundaries, functional units, and the selection of environmental impact categories. Data uncertainties and a lack of standardization limit the accuracy and comparability of the results.

Sečkár et al. provide a comparison between the *Ecoinvent* and *GaBi* databases as well as between the LCA software *SimaPro* and *GaBi*. The results indicate that different methods, modeling functions of the LCA software, and the choice of databases have a significant influence on the results. The differences are particularly evident in the transport sector, where individual environmental impacts can vary greatly. Even with identical inputs, different implementations of LCIA methods and differing characterization factors between the software tools can lead to significant deviations in the results [6:9]

In the context of sustainable lighting, there is an increasing focus on assessing the environmental impacts of LED luminaires during manufacturing and transportation. Given limited resources, the question arises as to whether the ongoing extraction of new raw materials is more environmentally sound than the recycling and reuse of materials at the end of the product life cycle [6:10]. A nuanced analysis of these processes is crucial for making informed decisions regarding material use, circular economy, and production strategies. At the same time, studies show that the vast majority of environmental impacts, particularly in terms of global warming potential, occur during the operational phase, with up to 99% attributable to operation [6:11,6:12]. This finding suggests that, despite the relevance of manufacturing and recycling processes, the greatest leverage for reducing environmental impacts lies in optimizing the usage phase. Measures such as energy-efficient design, smart control systems, or demand-based lighting concepts can make a decisive contribution here and should therefore become a greater focus of research and practice.

The energy-saving potential for lighting varies widely depending on the control systems used. Simply adjusting artificial lighting based on the availability of daylight can result in energy savings of between 20% and 70% for artificial lighting, depending on the specific conditions [6:13]. Concepts for controlling lighting based on occupancy can also significantly reduce the energy demand of artificial lighting. Therefore, further measures to reduce energy demand during operation prove to be essential. Approaches to this include adapting occupancy control (specifically the switch-off times associated with PIR sensors) to individual occupancy patterns, the use of zone-controllable lighting concepts, and the optimization of user distribution within the space in zone-controlled lighting concepts [6:14,6:15, 6:16].

With the operational phase being the relevant phase (see [6:11,6:12]), efficient planning, energy-conscious operation, proactive maintenance, and standardized data collection to identify opportunities for optimization also become increasingly important for reducing environmental impacts.

Although the majority of environmental impacts from artificial lighting occur during the operational phase, this does not apply to daylighting systems. In these systems, energy consumption during operation is minimal, so that the environmental impacts are predominantly concentrated in the manufacturing, installation, and disposal phases. Consequently, compared to electric light sources, the focus of environmental impact shifts to the life cycle phases outside of operation.

References Section 6

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7 Conclusions

While BIM is already an integral part of comprehensive construction planning in the AEC sector, using digital information from the BIM model presents users with significant challenges. The complexity of the BIM model is usually too high at the geometric level and must be simplified for the energy model. Some BEM tools for daylight and artificial lighting simulation already support geometry import via IFC, but the majority of tools do not. Alphanumeric information is supported by virtually no tool, and when it is, only minimally. In theory, BIM tools and their digital building models already support the ability to provide all the necessary information for a BIM2BEM process. In practice, however, the processes for defining and integrating information are often still cumbersome, and the legal framework within the BIM2BEM workflow is often unclear. These problems are already challenging enough. However, it must be acknowledged that on the software development side of the major BIM tools, much progress has been made toward openBIM, and significant work has also been done in research. Unfortunately, BEM tools, on the other hand, still feel like they are in their infancy, as they often rely on proprietary data formats and closed environments. Adaptation to open data exchange formats is limited and developing slowly. Although much is being done in academic research, software manufacturers are now also being invited to take further steps to make these processes universally applicable and widely available.

LCA for lighting systems provides valuable insights into environmental impacts across the life cycle and highlights the critical role of the operational phase. At the same time, differences in databases and a lack of comparability between lighting concepts in particular reveal unclear generation of secondary data, insufficient modelling of transport, and a lack of guidance for the use phase and the end-of-life phase, which limits the ability to verify the results, including the LCA background calculations. The LCA should not be used as the sole criterion for sustainability. Rather, it should be used in combination with other evaluation methods and in consideration of a broader range of environmental and usage parameters. There is a significantly greater need for transparency regarding the databases used and the methodology. In addition, an integrated building assessment tool is required that enables energy and environmental analyses for various lighting concepts.

The consistent integration of control systems into BIM enables a seamless, efficient, and collaborative planning and operations process. An open workflow minimizes information loss, while the automatic generation of control logic, wiring diagrams, and commissioning procedures reduces errors and on-site effort. The bidirectional coupling of design and operations feeds operational data back into the digital twin, enabling continuous optimization and robust performance monitoring of design decisions, thereby improving energy efficiency and user comfort. Open interfaces and system-independent approaches promote cross-disciplinary collaboration, increase design reliability, and contribute to digital and sustainable transformation throughout the entire building lifecycle.

The convergence of BIM, energy simulation, lighting analysis, life-cycle analysis, and operational digital twin approaches is proving to be a key prerequisite for sustainable design, construction, and operation. The findings of this report show that technical potential cannot be scaled without robust interoperability standards and semantically consistent, cross-disciplinary data models. Equally crucial are consistent parameter definitions and quality-assured data pipelines that reliably support the flow of information from early design through to operation. Additionally, organizational prerequisites in the form of competencies, established processes, and effective governance are needed to leverage the socio-technical potential of BIM and create a robust decision-making basis for performance-based planning.

Priority research and development areas lie in the harmonization of data models and mappings between BIM, lighting and energy simulation, and LCA. The validation of dynamic control strategies for daylight and artificial lighting in coupled workflows and the operationalization of digital twins with standardized semantics are also necessary research objectives. Advances in these areas will enhance planning quality, increase the reliability of simulation results, and measurably improve the environmental performance of the built environment.