Information Delivery Manual (IDM) Development for Building Information Modelling (BIM) and Building Energy Modelling (BEM) Workflows

Also known as:

“Technical Report for BIM-BEM Workflows”

A technical report providing an overview of requirements for developing IDMs and corresponding data exchange specifications between building information modelling and building energy modelling, simulation, and analysis throughout a project lifecycle

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… Richard Kelly for his support, confidence, and seemingly endless patience in seeing the project take a sharp turn in direction and extended duration, but in a way that I hope best serves the community through the maturing bSI Process;

… the Building Room Steering Committee and Project Steering Committee for their patience;

I offer this report with gratitude in the trust placed in me, even though I am not a BEM Subject Matter Expert, but keenly appreciative of the complexity of the issue and the need for its proper resolution.

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Jeffrey W. Ouellette
Progress Advocate for the Built Asset Industry

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Glossary

Term	Abbreviation	Definition / Summary
Building Energy Model or Modelling	BEM	Similar to “Building Information Model/Modeling (BIM)”, a commonly used term to describe the data model and/or all the processes, tools, and data modeling that are a part of determining the usage of energy during the operational phase of a building.
Building Energy Performance Simulation	BEPS	A synonym to BEM
Building Information Model or Modelling	BIM	BIM may refer to the data model describing a building and all information related to its physical construct, the processes necessary to design, procure, construct, and operate, the people and roles necessary to carry out processes and responsibilities, and … BIM may also refer to the process of gathering information, creating, and editing the data model, as well as the uses of the data model and information throughout the life cycle of the building project.
Building Performance Simulation	BPS	May be used as a synonym to BEPS, but usually includes other aspects of performance beyond energy usage, such as physical wear, ….
Building Room	BR	Open forum within bSI responsible for the building domain and all developments on IFC within this domain.
Building Room Project Steering Committee	BRPSC	Body within the Building Room responsible for managing the Building Room projects, meets once a month and Project Lead presents the Project Dashboard during this meeting.
Building Room Steering Committee	BRSC	Steers the Building Room and is responsible for setting out strategy, managing initiatives, and liaisons with other Rooms and bodies.
Business Process Modeling Notation	BPMN	A notation for use in the development of business process diagrams that is readily understandable by all business users, from the business analysts that create the initial drafts of the processes, to the technical developers responsible for implementing the technology that will perform those processes, and finally, to the business people who will manage and monitor those processes. Consists of Tasks, Sub-Tasks and Swimlanes etc. It describes Process Sequence in a visual form.
buildingSMART International	bSI	buildingSMART is a global community of chapters, members, partners and sponsors, driving the digital transformation of the built asset environment, through creation and adoption of open, international standards for infrastructure and buildings.
Construction Building Operations Information Exchange	COBie	Subset of an IFC Schema, so called MVD (Model View Definition) and defines non-geometric attributes for facility management requirements.
Computational Fluid Dynamics	CFD	The science of determining a numerical solution to the governing equations of fluid flow whilst advancing the solution through space or time to obtain a numerical description of the complete flow field of interest
Expert Panel	EP	Brings in expert feedback during the project, on a voluntary basis, during four meetings per year, on average.

Term	Abbreviation	Definition / Summary
Exchange Requirements	ER	The set of information that needs to be exchanged to support a particular business requirement at a particular project stage (or stages). The purpose of an exchange requirement is to describe the information that must be passed from one business process to enable another business process to happen.
Finite Element Analysis	FEA	FEA is a numerical method to predict behaviour of the assembly or a building and also a building part under curtain conditions.
Finite Element Modeling	FEM	Synonym of FEA
Geographic Information System	GIS	GIS is a computer system of geographic data for mapping, capturing, checking, and visualizing data related to positions on Earth’s surface.
Information Delivery Manual	IDM	An ISO 29481 Standard and Method to describe the BIM processes and their information exchange requirements of the individual BIM Use Cases or specific one. It could be an analogy of a recipe, which describes Who is delivering information, What is being delivered, When and How would it be delivered.
Information Exchange	IE	The exchange of information between computer applications; typically using a data exchange file.
International Standardization Organization	ISO	Please follow this link for more information: http://www.iso.org/iso/home.html
Model View Definition	MVD	A subset of the overall data model schema defining needed classes, properties, and values. The MVD is a formal translation of the Exchange Requirements defined in the IDM to a specific data model schema (e.g. IFC or gbXML). In a simple language its a "Filter", which sorts out information that e. g. Sustainability Consultant doesn't need in his/her simulations.
Open Geospatial Consortium	OGC	Please follow this link for more information: http://www.opengeospatial.org/
Project Leader	PL	Responsible for managing the project and ensures the project is delivered within budget and on time.
Project Team	PT	Executes a project based on a project plan and delivers the results according to plan.
Standards Committee	SC	The senior governance body within bSI overseeing the standards process. It will comprise representatives from members and chapters.
Standards Committee Executive	SCE	Establishes and manages the bSI standards process and addresses procedural and programmatic issues.
Standards Committee Technical Executive	SCTE	Provides technical advice to the SC and SCE the bSI standards process and addresses project technical issues.

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1 Executive Summary

The general application of energy analysis – also known as *building energy modelling* (BEM), *building energy performance simulation* (BEPS), or *building performance simulation* (BPS) – in building science is to use computer simulations to predict the energy usage performance of a design. It has gained increasing attention since the advent of Computer-Aided Design and Drafting (CADD) and the further evolution to Building Information Modelling (BIM). By looking at a range of simulations, invested stakeholders can guide subsequent design, procurement, construction, and operations decisions to better meet performance goals. But efforts to standardize processes for creating and exchanging needed data, as well as standardizing the data itself, have not been trivial, as many competing factors and interests affect such initiatives.

This report examines previous initiatives, as well as past and current influencing factors, both inside and outside the buildingSMART community, with the purpose of formulating a roadmap for moving forward in a more cohesive, harmonized direction based on buildingSMART principles of open, neutral, and international consensus solutions. The usual buildingSMART community sentiment is to focus solutions on the use of the IFC schema to provide the necessary semantics and mechanisms for data exchange (via data exchange specifications [e.g., MVD or IDS] and IFC-SPF, XML, or other serializations). This report recommends the buildingSMART community consider ALL potential options for determining the optimal means and methods of data capture and exchange for BIM-BEM processes, including the use, reference, or linking of other data schemas and methods that may have already proven their effectiveness.

While achieving an international consensus on detailed BIM-BEM workflow and data exchange standards may be a daunting task, it is possible to develop common understanding of the various workflows and inherent values of standardized data capture and exchange. From there, it may be possible to agree to more general, but still focused, frameworks for each of the steps in which BEM is valuable along the lifecycle of a built asset project delivered with a BIM-, or model-, based approach. These frameworks may allow for differing markets to apply generally agreed principles to regional or jurisdictional specific means and methods without contradiction to any others. Such frameworks or guidelines will still be valuable in guiding the software marketplace and domain experts in providing solutions to asset owners around the world with a narrower band of variation and complexity.

Finally, this report makes various recommendations for the buildingSMART community to use as a starting point for the consensus process and further development of detailed BIM-BEM processes and data exchange documentation. It is hoped by the authors that this will provide a springboard for said development, enabling simultaneous efforts by domain experts and stakeholders to tackle the many identified opportunities.

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2 Introduction

This report was created to respond to the previous effort by Tim Chipman to produce an IFC4-based Energy Modelling Model View Definition (MVD) as contracted by the Norwegian Building Authority. However, Mr. Chipman was unable to complete his effort and the project was turned over to Jeffrey W. Ouellette to continue with execution.

The original scope of the project, as described in the document "*IFC-EnergyAnalysis-WorkingDocument.docx*"[1] was described as:

> *Overall scope is to capture the building envelope and space boundaries within with sufficient information to run "baseline" energy analysis estimates.*
>
> *Scope does not include HVAC systems, ductwork, piping, or equipment -- perhaps that could be in scope for a future project, but not this one.*
>
> *Goal is not to create a lengthy specification, but something that can be well understood and rapidly implemented.*
>
> *This could fit in as an "add-on" information exchange that would be in addition to the IFC Reference View, i.e. vendors could provide option for supporting it as a checkbox, as some do now.*
>
> *Some of the additions to this information exchange may be helped by new data structures in IFC4 (e.g., IfcRelSpaceBoundary2ndLevel, IfcExternalSpatialElement, IfcSpatialZone) We might also identify new data structures or new ways of using existing data structures (e.g., use IfcMaterialLayerSet for glass panes within windows).*

The project was further formalized with an Activity Proposal "IFC4-Energy-View-For-Thermal-Boundaries.pdf" dated 2017-01-26, where the "Scope/Statement of Work" was further clarified as:

> *The scope includes developing a software specification (Model View Definition) that adds on to the IFC4 Design Transfer View by including (a) space boundary relationships between spaces and surrounding walls (including curtain walls), floors, ceilings, roofs, doors, and windows; (b) general material classification with thermal and solar properties; (c) indication of exterior exposure to air, earth, or water; (d) geolocation of building to determine climate conditions.*
>
> *One example file will be included consisting of a very simple building of rectangular shape having a single level with slab on grade, walls with windows exposed to the sun, and a roof with a skylight.*

[1] Refer to folder "Previous_project_materials" for document

The scope does NOT include classification of spaces (as would be needed to determine baseline energy requirements), internal gains (such as from people or equipment), occupancy schedules, weather schedules, electrical loads, zones, systems, ductwork, piping, or HVAC equipment. Future specifications could build upon this project to capture such additional scope.

By the time the project was turned over to Mr. Ouellette at the buildingSMART International Standards and Solution Summit in Tokyo, October 2018, a workflow analysis had been documented[2] by Jean Carrière, founder of Trailloop, a BEM expert with high proficiency in the use of the IES-Virtual Environment platform. The analysis attempted to determine the optimal workflow, and document any current deficiencies, in the creation and transfer of BIM data from a BIM-authoring tool (Autodesk Revit) to a BEM tool (IES-VE 2018) to perform needed simulation and analysis. The resulting report indicated several issues in the native BIM data and resulting model data transfer (using an early version of IFC4 export with 2nd level space boundaries). But the effort did not dictate nor dissuade any particular course of action.

The IDM specified in the Activity Proposal was not yet present. No vendors had yet been committed to supporting further development and support of the project.

At the Tokyo Summit, a presentation was delivered focusing on the proposal to use the IFC4 Design Transfer View (DTV 1.0) with some additional requirements for BEM including analytical elements as defined in IFC (e.g., *IfcThermalBoundary, IfcThermalLoad, IfcThermalZone*). The issues with such a conclusion were two-fold; (a) that software vendors were currently focused on IFC4 Reference View certification and not in a position to simultaneously tackle DTV support and certification and (b) a growing consensus that the DTV 1.0 was not defined well enough to implement in software due to its ambiguity in use cases[3].

2.1 A Renewed Approach

Upon further evaluation by Mr. Ouellette and the bSI Management Office, as well as the Building Room Steering Committee, the original scope and effort of the project was judged as being insufficient and not adhering to the bSI Process. To develop the desired *international standard* of a Building Energy Modelling information exchange for essentially a construction-to-owner handover, the project was lacking sufficient scope, international input, and core research to determine if such a proposal could result in an international standard product to meet multi-market needs and standards. The original project started with many generalized assumptions that seem to ignore

[2] See “IFC_Energy_Model-Trailloop.pdf”

[3] The concept of ***design transfer***, in which as many data points (e.g., parameters) as possible are delivered via IFC-based file transfer, was determined to be too broad in scope, as the end use cases could have different requirements for level of detail, or level of information, for each element depending on how the data was to be used by the receiver. In addition, there are many building elements in the IFC4 schema which do not contain enough detail to enable a ***parametric transfer*** without significant addition of custom properties and property sets (e.g., stairs, ramps, roofs, and curtains walls).

or obfuscate the complexity of BIM-BEM interactions across an entire lifecycle of a project, accommodating many different levels of simulation and analysis, across many different requirements in a multitude of jurisdictions, and use of many different types and complexities of software in both BIM authoring and consumption for BEM simulation and analysis.

In addition, the development and rollout of the buildingSMART International Technical Roadmap has introduced new technical concepts for further improvements in digital interoperability through considerations for alternatives to the traditional monolithic, IFC file-based, MVD-defined data exchange. Such concepts include a UML-based schema definition, additional serializations such as JSON, definition of data exchange requirements though an Information Delivery Specification (IDS), and integration of the buildingSMART Data Dictionary (bSDD). This directly impacts any further work done in this particular domain and the technical expectations end users and software vendors will have in the delivery of data exchange requirements as well as the methods and formats for the data exchanges themselves. These new aspirations and corresponding technical developments will need serious consideration in the decisions of the method, content, and timing of delivery of resulting domain data exchange requirements.

In turn, Mr. Ouellette has worked with the other project team members to produce a high-level overview of the BEM process, sub-processes, requirements, workflows, software, and methodologies necessary to produce not just one, but potentially multiple data exchange specifications for the entire lifecycle of a built asset project.

2.2 A BIM-BEM Roadmap

The result is a report that acts as a high-level BIM-BEM Roadmap, or *über-IDM*, to confirm the problem being addressed, expose all the relevant aspects relating to the problem and possible solutions, and describe the most appropriate methodology for subsequent efforts to tackle solutions. Instead of generating a single Model View Definition (MVD), this report steps back to look at how the Building Information and Building Energy Modelling (BIM-BEM) processes, data requirements, and associated technologies appear and change throughout the entire lifecycle of a project, from initial conception to design and construction, and through operations. From the conclusions and recommendations of the report, it is hoped that a singular international effort can be undertaken to establish common standards, possibly as frameworks rather than exacting specifications, to enable BIM-BEM workflows on a highly consistent and high-quality basis. It is hoped that this will help vendors in developing the most useful tools and functionality in leveraging BIM-based data for the global marketplace for consistent output and results.

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3 Problem Statement

The general application of energy analysis, or *building energy modelling* (BEM), also known as *building performance simulation* (BPS), in building science is to use computer simulations to *measure* performance of a design[4]. By looking at a range of simulations, invested stakeholders can guide subsequent design, procurement, construction, and operations decisions to better meet performance goals. Developing BIM-BEM interoperability business cases, standardizing processes for creating and exchanging needed data, and standardizing the data itself is not a trivial task as many competing factors affect the process. These factors/challenges will be described in the following sub-sections.

3.1 Inconsistent Project Delivery Processes

Throughout the history of buildings, the methods by which such projects were delivered has continually evolved and split into many different modern business/process models. As such, there is no single standard means in which the information developed to build the project (design) and the method in which it is built (construction) and turned over to the owner (operations). The lack of a modern single legal standard, as well as tenuous agreement on several different possible legal methods (e.g., Design-Bid-Build, Design-Build, Design/Contractor-at-Risk-Build, various flavours of Integrated Project Delivery, etc.) make for challenges in the quality and thoroughness in which project delivery information is created, shared, and used.

In the modern era, we have seen a tradition of the master design/builder evolve into contemporary professions of architect (the design professional) and contractor (the construction professional). On top of that, we have seen the varying roles of design (e.g., engineering, lighting, environmental, etc.) split into further specialty professions and services (aka consultancies), as well as the numerous trades (e.g., concrete, steel, HVAC ducting/sheet metal, plumbing, electrical, interior finish carpentry, etc.) that make up the team behind the contractor. This plethora of professionals further adds to the complexity of project delivery information creation, exchange (if at all), and use.

In the classic/traditional approach for designing a building (Design-Bid-Build), architects/designers will start with the project formal concept and pass a version to other consulting disciplines, such as building services (mechanical, electrical, and plumbing) and structural engineers, and energy consultants. Parallel processes of design, simulation, and analysis then take place as the designer continues to refine aesthetic and programmatic solutions per the client's direction and the consulting

[4] 'measure' as opposed to 'predict'. At this point in time, the inability to accurately predict a building's real-world performance based on BEM/BPS has come to a reckoning due to several mitigating factors as pointed out in Section 3.2.

parties develop their strategies and designs to suit the project requirements. At some points, these parallel packages of information must be delivered to the designer, who must decide if and how to incorporate this information that may further affect their formal design decisions. Reiterations of this process occur again and again until the designer feels the project has reached the design goals set forth by the client or until calendar and or budget constraints prevent further iterations.

This process can be very inefficient due to the asynchronous development of information from so many different points of view/domains/disciplines, usually complied and delivered to each other in large, monolithic packages, with information that may be conflicting in their form and recommendations, and delivery of the packages taking different periods of time and effort. As a result, it can be difficult to coordinate the various results into a single solution. This information is then handed off to the construction team, which may further edit or augment such information to meet cost limits, procurement challenges, or changes directed by the owner. The collection of such costing, procurement, and construction processes may also be inconsistent in its quality and comprehensiveness. Sadly, this inefficient traditional approach is the norm across many markets, even so far as encoded into law for public projects, because traditions are so difficult to change in the global built asset industry.

In the more idealized **Integrated Project Delivery (IPD)** methodology[5], all parties are subject to operating as a single entity/team, including the owner, to better facilitate the creation, exchange, and use of information among various subject matter experts and professional disciplines. The intent is to reduce, if not outright eliminate, the typical problems of siloed information and inconsistent exchange between stakeholders and phases of the project. However, even though IPD as a legal construct has been around for nearly 15 years, it is not commonplace as there may be cultural reluctance, and even legal restrictions, against its implementation.

3.2 Discrepancies Between Reality and Idealized Models

While the point of simulation and analysis is to guide a design to meet performance and/or sustainability targets, there is a fundamental difference between the predictions of simulation tools and the reality of how a building actually performs. Simulations are based on idealized models of human behaviour and comfort, climate[6], building product performance[7], and technical energy consumption[8].

[5] See https://www.agc.org/integrated-project-delivery, https://leanipd.com/integrated-project-delivery/, and https://www.aiacontracts.org/contract-doc-pages/27166-integrated-project-delivery-ipd-family

[6] Per dictionary by Merriam-Webster "2a: the average course or condition of the weather at a place usually over a period of years as exhibited by temperature, wind velocity, and precipitation"

[7] Per the website Designing Building Wiki, "The term 'thermal performance' generally relates to the efficiency with which something retains, or prevents the passage of heat. Typically, this is in relation to the thermal conductivity of materials or assemblies of materials."

Individual lighting and temperature preferences, occupancy (humans are a significant source of local heat generation, as well as interactive behaviour with building systems), and equipment usage are simplified, often idealized, in models. Simulations use nominal material properties that are often linearized across a desired range. In reality, installations are complex, and localized factors (such as minor component variances) can impact performance. Simulations are also based on climate data, which is accurate over longer time scales. Daily performance, on the other hand, is based on localized weather, which is far more variable and increasingly less predictable than the averaged climate data.

When taken together, these and similar factors mean that simulations are preferably used and understood as comparative tools to help select between design options rather than to specify the absolute values of expected performance of a specific design decision, which can be misleading to non-technical stakeholders.

3.3 Varied Requirements by Jurisdiction

The role of energy analysis also varies greatly from jurisdiction to jurisdiction, including its optional use, prescribed methodologies and tools, regional climatic variations, and fiscal incentives/penalties for compliance.

Some have specific building code requirements (minimum standards of construction type and quality like insulation values, e.g., ‘R’ or ‘U’-values) to influence energy usage in new and/or retrofit construction and don’t require a BEM simulation and analysis. Meeting the minimum requirements is considered ‘enough’. Others may offer incentives to go beyond the minimum requirements and meet other prescriptive construction type, material, and system performance requirements, but also in no need of a BEM simulation and analysis. Still others may have broad, industry-led construction and/or performance targets/guidelines, but there is no specific enforcement mechanism and compliance is more ad-hoc. On the other end, in some BEM may be a requirement of one type of construction/occupancy/use, but not another (e.g., commercial office vs, single-family residential vs. multi-family residential vs. industrial) and have a preferred methodology or tools for execution at prescribed phases in the project design and delivery.

Different geographic regions may also have wildly different drivers due to climate zone. Some locations, such as Northern Europe, the Scandinavian countries, Northern China, or much of Canada and Russia, are heating dominated. Still others, such as the Middle East and South Asia, are cooling dominated. Some regions, such as the United States and Southern European countries, have locations where both heating and cooling are equally important. And large countries like the US and China

[8] This includes many different forms and sources of energy supplied, including, but not limited to electrical (nuclear-, coal-, natural gas-, solar-, hydro-, and/or biofuel-generated), natural gas, fuel-cell, or geothermal, generated either off-site and delivered or on-site.

may have all varieties of climatic conditions and all the different heating/cooling dominate situations, increasing the complexity of initiating standard requirements.

Local, state, regional, and/or national financial subsidies[9] may also influence the use of BEM and the resulting ROI of implementing energy efficient/sustainable strategies in the project's construction and/or retrofit. Such subsidies may significantly offset installation/replacement costs of particular systems while resulting in lower lifecycle costs (e.g., utility charges) to improve the owner's ROI timeline.

In jurisdictions where energy use must comply with a stricter code requirement, energy performance will have a higher priority as a design requirement. While this statement may appear facile, it is worth remembering, especially as energy performance often involves a trade-off of short-term cost vs. long-term benefit.

3.4 Varied Requirements by Standard / Protocol

There are various standards or protocols which prescribe requirements, as shown in **Appendix B – Building Energy Efficiency Standards / Protocols** which provides an extensive list of energy standards and certification protocols used throughout the world. These vary in specific targets or ranges acceptable for compliance, as well as varying in determining which factors are important for such compliance. Jurisdictions may apply one or more of these standards depending on occupancy type (single-family residential, multi-family residential, office, mixed use, industrial) or construction being new or a retrofit / rehabilitation.

These standards may vary in detail, but they generally prescribe low energy usage via design strategies and high-performance targets of components and mechanical systems. These may also include criteria for water usage, landscaping, and services like recycling and transportation. Some protocols/certifications grade designs on a point system with varying degrees of *green-ness*. Others mandate a minimum target of reduced energy usage over typical baseline specifications.

Another challenge of such standards / protocols is the possibility that these normative specifications partly contradict each other in varying degrees of severity, especially where multiple specifications might be applicable to a project because of physical location (with varying authority or multiple authorities having jurisdiction) or project type (e.g., residential, multi-family, commercial office, etc.).

3.5 Varied Responsibility or Liability

Depending on the individual construction project, responsibility for energy analysis may differ, being led by an architect, an engineer, or a specialized design consultant, each with a different focus and approach. Jurisdictional regulations may also determine responsibility for meeting code requirements and providing

[9] As an example, refer to Italian programs found here: https://www.mise.gov.it/index.php/en/energia/efficienza-energetica/incentivi

validated/certified and professionally liable information. At the same time, there is a need to ensure that all the different professional standards of care align with the vast variety of design and construction knowledge, such as responsibility for material and system selections, where it is properly documented, by whom, and who has the ultimate final decisions in determining what is designed among the many options and then executed. For example, if an architect is working with a BEM consultant and HVAC engineer in deciding to use a particular passive cooling system, the models and project deliverables specify such a system (which has a direct correlation to architectural, structural and other active and passive building systems), but the contractor decides to override the design with a less complex and expensive option during bidding and installation, the liability for the results on the entire performance of the building need to be fully understood by all parties.

There is also an issue of determining where/when a simulation model needs to be generated in the process. Some projects will require simulation be started during pre-design and carried through design as BEM simulation and analysis can have significant impact on design decisions. The general concept of BIM is that more information that is developed and used earlier in the design process has greater impact and lower cost/effort than trying to make design changes nearing the completion of design documentation deliverables and during procurement. However, other projects may conduct simulation and analysis only closer to the end of design as a validation step against benchmarks or regulations. Owners/Operators as well may require a simulation be conducted to assist in commissioning or as a post-occupancy step to help verify performance.

3.6 Variable Return on Investment (ROI)

The ROI of not just BEM, but of the resulting design and construction implementations may vary between locations/jurisdictions, projects, and owners. Regulations and specific energy efficiency requirements may drive costs that the owner has no choice to bear and influence the overall scope or scale of a project. Volatility of material/component pricing due to the length of the project delivery process is also a factor, as well as uncertainty or inconsistency of the supply chain from external economic, political, or other factors (e.g., weather events, pandemics, etc.). This includes energy source supply and costs, where fuel supply has a direct impact on market-driven pricing and can be adversely impacted by numerous conditions of scarcity or abundance (e.g., weather or political events destroying/hindering fuel supply, transmission, or storage capabilities, thus impacting prices). While BIM enables the ability to embed cost values (include carbon cost) directly into the elements of the model, external forces may render the validity of such information useless over any period up to the commissioning/handover of the facility.

3.7 Variety of Methodologies and Technologies

3.7.1 BEM

Methods for building performance simulations have existed for well over 60 years, growing in sophistication with the advances of computer science and engineering, including white-box (physics-based), black-box (data-based), and grey-box (hybrid, often used for controls) models. Early methods included less complex single-zone, single-system, steady state calculations based on simple tabulation of building element quantities, thermal properties, climate parameters, and performance criteria. But in the last 30 years, increasingly powerful computing hardware and more complex algorithmic development has enabled model-centric, equation-based building simulations and analyses. Some of the early methods are still in use today and even prescribed by Building Energy Performance Standards and Protocols, as well as contemporary software.[10] The most sophisticated systems being developed in the last 10 years have advanced further into incorporating real-time, model-based simulations with computational fluid dynamics (CFD) and finite element analysis (FEA) using a variety of connected and integrated algorithms.

In addition, there are the differences in which optimal type of model to use for BEM, such as an analogous physical representation (aka, architectural model) or a thermal boundary abstraction (aka spaces and/or space boundaries/thermal surfaces), especially in relationship to BIM-based data. Different types of analyses benefit from different types of geometric representation (see discussion in subsections 5.4 General Information Requirements and 5.4.4 Building) of the asset being analysed. From the BIM side of the equation, a relatively accurate digital depiction of the physical structure is the norm with spatial concepts of Room and Storey often depicted as simplified volumes with needed data associated in textual attributes/properties. But some BEM platforms and/or methodologies don't require, nor are easily able, to consume such an intricate geometric data set. Instead, they are looking for simplified representations (planes, edges) where thermal conduction occurs.

The results of these different methods can vary in both small and large ways, depending on the granularity of data and scale of simulation. The method or tool which is best or most accurate may also depend on the type of simulation being required and when in the project delivery process but is also further exasperated by software vendors through their marketing and varied development. Some regulatory/standards agencies provide software testing and certification against baseline models and criteria, like the ASHRAE 90.1 baseline models from the United States of America Department of Energy (DOE).

[10] Refer to https://www.buildingenergysoftwaretools.com for a highly comprehensive listing of software tools available and used for many different aspects of BEM simulation and analysis.

Currently, there are many simulation tools that can be found throughout the industry, as shown in the table of **Appendix C – Building Energy Modelling Simulation & Analysis Engines**, but they have different underlying technologies (algorithms/simulation engines) and use different methodologies. While these tools are all focused on BEM, they also have different focuses of scale, detail, and process. This means that some tools may be more tuned to early design, with low levels of geometric detail and not suited for regulatory type modelling and reporting, while other excel in just the opposite way. Thus, multiple tools and methods might be used on a single project, depending on the stage of design development, project delivery, or operations. These tools also have varying regional dominance which make them the de-facto standard in one region and practically unused in another.

3.7.2 BIM

Many times, BIM is seen as a natural extension of IPD, but the technology and processes of BIM are independent of project delivery method. As such, there is not necessarily an inevitable efficiency in 'using BIM' because the technologies and processes are as diverse, if not more so, as the number of stakeholders and project delivery methods available[11]. Often, BIM is romanticized as a 'single source of truth' with all parties working within a single data model, but this notion has quickly been debunked by efforts and failures to integrate technologies and legal responsibilities in a practical way.

Now, the prevailing view is that BIM is a process where information is generated in many different corners of the project delivery stakeholders, but potentially federated, or linked, in meaningful ways to serve the purpose of centralizing access to relevant, timely information at any given point of time in the project delivery process. Such federation accepts that information (typically models) may be developed with different technologies and formats often widely disparate from each other, but great efforts are needed to link them together in a meaningful way.

3.8 Ineffective BIM-BEM Interoperability

The main goal of this report is to point the built asset industry in a direction to solve the biggest issue, data/information interoperability between BIM and BEM tools and processes. As pointed out, there are a great number of tools/platforms available for BEM. There are even more used throughout the industry for the generation of BIM data/models that contain the information that could be used by BEM tools, as well as benefit from the results generated by BEM. However, general interoperability, even among BIM tools/platforms, has plagued the industry for decades, regardless of the best efforts of buildingSMART International, its chapters, and their invested members. As documented in the following section, 4 Precedent Efforts, a good

[11] For example, see https://technical.buildingsmart.org/resources/software-implementations/ for a list of BIM tools/platforms/utilities that have some bSI standards (IFC, BCF) support. While the list is large, it still only represents a fraction of the BIM tools available on the global marketplace.

number of previous efforts have attempted to make use of contemporary and inventive solutions to improve interoperability between BIM and BEM tools and workflows. Not all are necessarily abject failures but given that this document is written to spur a global, cross industry effort to address the challenge, there is an opportunity to examine what has worked, what is working, what could work, what methods are available, and what may be consensus on best practices and standards to enable effective BIM-BEM interoperability.

Creating new or leveraging existing standards to technically connect tools and platforms is only one part of the challenge. The other significant, if not more difficult, challenge is then getting stakeholders in various projects around the industry and the globe to adopt, deploy, and implement said practices and standards to enable effective, consistent, and reliable BIM-BEM data exchanges. Cultural changes, including business process changes, are often found to be the biggest obstacle, bigger in scope and more onerous in changing minds.

4 Precedent Efforts

Approaches to addressing the complexity of BEM and attempts to utilize models and BIM-based processes for simulation and analysis have been ongoing for a number of years. This includes previous efforts to develop IFC-based solutions, which had varying degrees of implementation and research to explore approaches to BEM from many different points of view. Also included are efforts from organizations outside buildingSMART International, usually approaching the challenge from the BEM domain expert point of view (e.g., IBPSA, USDOE, IEA, etc.)

4.1 IFC-based IDMs / MVDs

While the previously stated factors complicate the creation of an Information Delivery Manual (IDM) for identifying data exchanges for model-based energy analysis for buildings, it is also clear that there is no solitary use case. In fact, IDMs focused on IFC-based data and exchanges have been proposed in the past with varying levels of completeness and adoption. The most significant are summarized in the following table[12]:

Table 1: Previously Developed IFC-based IDMs / MVDs for BIM-to-BEM and related workflows

IDM / MVD ID	IDM / MVD Title	Status (bSI and non bSI)	Focus
BSA-002	Design to Energy Performance Analysis	bSI: Draft	Ideal for design applications (IFC2x3)
GSA-003	Architectural Design to Building Energy Analysis	bSI: Draft / candidate GSA: Approved	Architectural design to indoor climate simulation (IFC2x3)
GSA-005	Concept Design BIM 2010	bS alliance (US/CA): Draft	Multiple concept design validation workflows in one exchange (IFC2x3)
NOW-001	Nordic Energy Analysis	bSI: Approved	Derivative of GSA-003 (IFC2x3)
HUT_HVAC-002	Space Requirements and Targets to Thermal Simulation	bSI: Draft	Utilizing indoor climate and energy simulations (IFC2x3)
HESMOS	Design to Energy simulation and Energy related Operation Costs	bSI: Draft	(IFC2x3)
COBie	Construction Operations Building Information Exchange	NBIMS-US v3	Handover data (IFC2x3 and tabular) of finished project construction from contractor to owner/operator

[12] Documentation can be found within the “Research-Reference” folder provided as supporting material for this report.

IDM / MVD ID	IDM / MVD Title	Status (bSI and non bSI)	Focus
HVACie	Mechanical System Design	NBIMS-US v3	COBie subset (IFC4 and tabular) specific to mechanical (HVAC) systems
SPARKie	Electrical System Design	NBIMS-US v3	COBie subset (IFC4 and tabular) specific to electrical (power, lighting) systems
WSie	Plumbing System Design	NBIMS-US v3	COBie subset (IFC4 and tabular) specific to plumbing (supply, waste) systems
CV2.0 + SB1.1	Coordination View 2.0 plus Space Boundary Addon View 1.1	bSI: Approved Standard	Coordination (IFC2x3) between building design disciplines (architecture, structural, and building services) + addon for including geometry and data for boundaries of room/building surfaces (e.g., floors, walls, ceilings, doors, windows, etc.)
RV1.2	Reference View v1.2	bSI: Approved Standard	Coordination (IFC4) between building design disciplines (architecture, structural, and building services) with simplified geometry requirements

4.1.1 BSA-002 Design to Energy Performance Analysis

BSA-002 “Design to Energy Performance Analysis”[13] was proposed in 2008 as a draft IDM for IFC2x3, but ultimately was incorporated into the work of GSA-003 and GSA-005 for further development. The development during GSA-003 was then added to the 2015 National BIM Standard-United States® Version 3 (NBIMS-US v3)[14] by the US National Institute of Building Science’s (NIBS)[15]. For more info, please refer to GSA-003.

Because it was a draft specification and later rolled into GSA-003, it does not appear to be supported by software. This MVD *might* be available to some users and platforms as an optional add-on or custom setting from respective software vendor customer support services.

[13] Documentation can be found within the “Research-Reference > IDM-GSA > GSA-005” folder or at http://www.blis-project.org/IAI-MVD/IDM/BSA-002/PM_BSA-002.pdf

[14] See https://www.nationalbimstandard.org/

[15] See https://nibs.org/

4.1.2 GSA-003 – Architectural Design to Building Energy Analysis (BEA)

This IFC2x3 IDM[16] by the U.S. General Services Administration (GSA)[17] focuses on energy analysis during design, especially documenting inputs into energy analysis tools. Key inputs are architectural, building, site, construction type, space boundaries, energy targets, HVAC, and daylighting.

GSA-003 defines the following exchanges:

- Energy Analysis Inputs 1
- Energy Analysis Inputs 2 (mechanical engineer/energy consultant)
- Energy Analysis Results

Energy Analysis Inputs 1 is described as "*Exchange of partial set of energy simulation input information for peak load sizing and annual energy consumption calculations. This data exchange requirement is completed by the architect*." This exchange requires general geometric information and generic material descriptions.

Energy Analysis Inputs 2 is described as "*Exchange of complete set of energy simulation input information for peak load sizing and annual energy consumption calculations. This data exchange requirement is completed by the mechanical engineer and/or energy consultant*." This exchange includes all of energy analysis inputs 1 as well as additional space and ventilation information, occupancy information.

Energy Analysis Results are described as "*Exchange of complete set of energy simulation output information including comfort metrics, peak load information, annual energy consumption, and utility rate information.*"

One aspect of GSA-003 is that material and thermal properties are explicitly expected to be obtained by using material tags and referencing property values from other data sources. Otherwise, thermal properties are optional. While this is a valid approach during design when an energy consultant or other subject matter expert is available, in other construction phases this may not be available, and that data may be missing. Energy analysis results exchange is also focussed on information needed by design experts and may not include the information needed by later phase use cases.

Overall GSA-003 was a good starting point as an IDM, however it is limited in overall scope to the design phase, with some utility in the pre-design phase. It was formally submitted and added to the NBIMS-US v3, but not widely supported by software. In fact, the MVDs is not currently found in any of the major BIM-authoring platform (ALLPLAN® Allplan® AEC, Autodesk® Revit®, Bentley® OpenBuildings™,

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[16] Documentation can be found within the "Research-Reference > IDM-GSA > GSA-003" folder or at http://www.blis-project.org/IAI-MVD/reporting/listMVDs_4.php?SRT=&MVD=GSA-003&DV=2

[17] See https://www.gsa.gov/ for more specific information about GSA's BIM efforts, see https://www.gsa.gov/real-estate/design-construction/3d4d-building-information-modeling

Graphisoft® Archicad®, or Vectorworks® Architect) IFC export interfaces. This MVD might be available to some platforms as an optional add-on or custom setting from respective vendor customer support sources.

4.1.3 GSA-005 – Concept Design BIM 2010

GSA-005 "Concept Design BIM 2010"[18], an IFC2x3 MVD containing the work of BSA-002 and GSA-003, was developed as candidate standard buildingSMART alliance IDM. The intent of GSA-005 was to exchange building models to be used in four different concurrent workflows seen as having a high value to the GSA in determining the feasibility and quality of a proposed design from multiple points of view including:

- Spatial Program Validation
- Circulation/Security Analysis
- Design to Energy Performance Analysis
- Quantity Take-off/Cost Estimating

The implementation of GSA-005 was carried out in a joint venture with buildingSMART alliance, the US chapter of buildingSMART at that time, and the Open Geospatial Consortium (OGC)[19] as the "AECOO-Phase 1 Testbed"[20]. The testbed involved several different vendors working side-by-side to develop the internal modelling and IFC export capabilities needed to produce the desired IFC models for the four feasibility analyses. Along with the MVD documentation, the GSA, with the help of participating vendors in the corresponding AECOO-1 Testbed project, created "GSA BIM Guide 05 – Energy Performance"[21] to assist model authors with the appropriate scope and detail in creating BIMs to be used for the exchange. The work of the testbed was used as implementation proof for submission of GSA-003 to NBIMS-US v3.

However, as summarized at the conclusion of the testbed[22], it appeared to be limited success for software to meet all the requirements to model and successfully export IFC models based on all four workflows. As of 2022, the Concept Design BIM 2010 MVD option for IFC export can be found in out-of-the-box versions of Archicad and

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[18] Documentation can be found within the "Research-Reference > IDM-GSA > GSA-005" folder or at http://www.blis-project.org/IAI-MVD/reporting/listMVDs_4.php?SRT=&MVD=GSA-005&DV=2

[19] See https://www.ogc.org/

[20] See http://xml.coverpages.org/OGC-buildingSMART-AECOO1.html and https://www.ogc.org/projects/initiatives/aecoo-1

[21] Documentation can be found within the "Research-Reference > IDM-GSA > GSA-005" folder or at https://www.gsa.gov/real-estate/design-construction/3d4d-building-information-modeling/bim-library

[22] Documentation can be found within the "Research-Reference > IDM-GSA > GSA-005" folder or at https://portal.opengeospatial.org/files/?artifact_id=37223&version=3

Revit only but *might* be available to some users and platforms as an optional add-on or custom setting from respective software vendor customer support services.

4.1.4 NOW-001 – Nordic Energy Analysis

NOW-001[23] was completed in 2011 and is an IFC2x3 MVD description intended for architectural design to energy analysis in concept design stage by Norway's Statsbygg[24] and Finland's Senaatti[25]. It was based on the GSA-003/005 IDMs / MVDs. It has one exchange, and contains general project information, building location, building composition, spaces and heat transfer surfaces, mapping, and external shading. It does not include thermal properties of building elements, occupancy schedules, or weather data. It also does not include air handling information. It does not specify anything about the resulting simulations or intended use of the information.

This MVD shows the importance of scoping for an energy analysis MVD to a particular use case. The contained information provides good coverage for early design applications, where load calculations are required to help guide design decisions, but this MVD lacks extensibility that would make it useful for other use cases, such as determining the suitability of a project for refurbishment / recommissioning.

As it is a localized MVD, meant for utilization in Norwegian and Finnish public projects, in 2022 there does not appear to be wide availability in major BIM-authoring platforms but *might* be available to some users and platforms as an optional add-on or custom setting from respective software vendor customer support services.

4.1.5 HUT_HVAC-002 – Space Requirements and Targets to Thermal Simulation

The HVAC Laboratory at the Helsinki University of Technology presented a draft IFC2x3 MVD[26] (no full IDM documentation available) in May 2008 where "*Building requirements and targets can be used in thermal simulations as an input or for validation of the simulated solutions. Requirements and targets are needed both for indoor climate and energy consumption simulations.*" It had a very limited set of information to be exchanged and proposed the exchanged could be used at any stage of design.

As it is a localized MVD, meant for utilization in Norwegian and Finnish public projects, there does not appear to be wide availability in major BIM-authoring

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[23] Documentation can be found within the "Research-Reference > IDM-Nordic" folder or at http://www.blis-project.org/IAI-MVD/reporting/listMVDs_4.php?SRT=&MVD=NOW-001&DV=2

[24] See https://www.statsbygg.no/

[25] See https://www.senaatti.fi/

[26] Documentation can be found within the "Research-Reference > IDM-HUT" folder or at http://www.blis-project.org/IAI-MVD/reporting/listMVDs_4.php?SRT=&MVD=HUT_HVAC-002&DV=2

platforms but *might* be available to some users and platforms as an optional add-on or custom setting from respective software vendor customer support services.

4.1.6 HESMOS

HESMOS was a research project funded by the European Commission Seventh Framework Programme with the title:

> "ICT Platform for **H**olistic **E**nergy Efficiency **S**imulation and Lifecycle **M**anagement **o**f Public Use Facilitie**S**" (**HESMOS**).

It is an overall framework that seeks to match use cases to existing MVDs.

For example, this framework suggests[27] using IFC2x3 CV2.0 (Coordination view) for BIM to Energy and BIM Collaboration Format (BCF) to return simulation analysis reports to designers. The advantage of this approach is that by using well documented and adopted exchanges, it is easier for both users and tools to work with the known formats.

Conversely, while it may be reasonable to expect the formats to contain the expected information, but there will be an extra overhead for the recipients and senders to interpret and prepare the information that is being exchanged. For example, Coordination View has the needed elements for many energy analysis use cases, but it also contains significant information that would not be relevant. As it currently stands, there has been a tendency to look at energy analysis as a single use case and implement a *one-size-fits-all* approach to MVD development. Unfortunately, this approach has led to several competing definitions that have much overlap but are also less suited outside their range. For this reason, a better strategy may be to define multiple tailored exchanges as part of an overall energy analysis framework.

Support for this MVD beyond the prototyping stage from the project is unknown. It does not appear to be wide availability in major BIM-authoring platforms but *might* be available to some users and platforms as an optional add-on or custom setting from respective software vendor customer support services.

4.1.7 COBie v2.4 – Construction-Operations Building Information Exchange

While the primary function of the Construction-Operations Building Information Exchange (COBie)[28] MVD is to transfer all *as-built* information of the finished project from the project delivery team to the owner/operator, there are multiple uses of such data. Besides the obvious population of an asset/facility management (FMS) and/or computerized maintenance management system (CMMS), such data captures identity and performance data of all electrical, plumbing, and mechanical equipment

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[27] Documentation can be found within the "Research-Reference > IDM-HESMOS" folder or at https://cordis.europa.eu/project/id/260088

[28] See https://www.wbdg.org/bim/cobie and the US National BIM Standard at https://www.nationalbimstandard.org/

installed. This can be leveraged for BEM workflows in construction, handover, and operational phases where the exact as-built information is used to further specify all the necessary elements of a BEM (e.g., air handlers, lighting, thermostats, building control systems, etc.).

COBie is another component of NBIMS-US v3 and has seen some implementations outside the US, with adaptations for local requirements (e.g., UK). However, NIBS has asserted its IPR over the COBie specification and exclusive control of its future revisions/adaptations. In 2021, NIBS launched the NBIMS-US Version 4 effort[29] through the Building Information Management Council (BIMC)[30].

It is available in many, if not most, major BIM-authoring platforms as either/both a MVD option for IFC export or/and a spreadsheet export containing the necessary model data in a preformatted delivery.

4.1.8 The Children of COBie – HVACie, SPARKie, and WSie

Developed in 2013 and added to the NBIMS-US v3, the collective objectives of **HVACie – Mechanical System Design**[31], **SPARKie – Electrical System Design**[32], and **WSie – Plumbing System Design**[33] MVDs, were to document their respective assets (systems and components) to support:

- Registration based on an accurate schedule of manageable assets.
- Operations based on the connections within the systems to allow their prediction and commissioning.
- Maintenance based on detailed identification of the manageable assets and their manufacturers and model numbers.
- Replacement based on detailed schedules of the specifying properties of the manageable assets.

While not fully focused on wholistic building energy performance, the exchange, based on IFC4, was intended to satisfy needs for the operations and maintenance phase of a project. As subsets of COBie, with much the same information exchange requirements, but limited to their respective systems and components, they provide a wealth of detail of systems and components… some data which may also be needed

[29] See https://www.nibs.org/blog/bim-council-priorities-partnerships-national-bim-standard-us-v4-and-us-national-bim-program

[30] See https://www.nibs.org/bimc

[31] See http://docs.buildingsmartalliance.org/MVD_HVACIE/ and the US National BIM Standard at https://www.nationalbimstandard.org/

[32] See http://docs.buildingsmartalliance.org/MVD_SPARKIE/ and the US National BIM Standard at https://www.nationalbimstandard.org/

[33] See http://docs.buildingsmartalliance.org/MVD_WSIE/ and the US National BIM Standard at https://www.nationalbimstandard.org/

for detailed BEM workflows in the operations and potential recommissioning or decommissioning phases.

As localized MVDs, meant for utilization in US projects, there does not appear to be availability in any of the major BIM-authoring platforms. They *might* be available to some users and platforms as an optional add-on or custom setting from respective software vendor customer support services.

4.1.9 CV2.0 + SB1.1 – Coordination View v2.0 & Space Boundary Add-on View v1.1

In 2010, a new effort to certify software applications' abilities to exchange IFC2x3 files was undertaken by bSI and the Implementation Support Group (ISG), the former technical support forum of the bSI member software vendors. At that time, it was decided to develop a new MVD, the Coordination View 2.0 (CV2.0) along with optional addon views for Quantity Takeoff (QTO) and Space Boundaries (SB)[34]. CV2.0 addresses the coordination of design information between building domain disciplines (architecture, structural, and building services/MEP). This exchange could be used throughout the design process with varying levels of geometric and information detail.

However, the CV2.0 has been mis-applied by many users to workflows other than design coordination, with or without the add-on views. Its use as a general purpose has been misconstrued, and as such has been widely, and unfairly, criticized by many users for its inability to meet their non-prescribed needs for workflows the CV2.0 never meant to support, such as transfer of parametric element controls to enable system-to-system transfer of models from one native format to another for highly integrated model-based design processes or bidirectional transfer of model information.

As a product and basis of the bSI software certification process[35], the CV2.0 MVD has seen extensive certified export and import implementation from numerous BIM applications[36] of international or localized markets, as well as informal adoption lacking certification. It has a solid foundation in software implementation and real-world deployment and may be a good basis for developing other needed data exchanges based on IFC2x3.

4.1.10 RV1.2 – Reference View v1.2

With the revision of the IFC schema to IFC4, a new strategy was taken to software certification in support of IFC-based data exchange. Issues with CV2.0 and the coordination workflow were examined, highlighting the problem of geometry

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[34] See https://technical.buildingsmart.org/standards/ifc/mvd/mvd-database/ for links to MVD documentation

[35] See https://technical.buildingsmart.org/services/certification/ifc2x3-program/ and https://ifc2x3.b-cert.org/

[36] See https://www.buildingsmart.org/compliance/software-certification/certified-software/

interpretation and handling by numerous systems. It was decided to develop a new design coordination workflow based MVD that used simplified geometry but the same extents of object classes and information to reinforce the case of ***referencing*** external information in a BIM application and not attempting to translate into native fully parametric objects and models. The resulting Reference View version 1.2 (RV1.2)[37] became the new bSI software certification MVD for IFC4[38].

Like the IFC2x3 CV2.0, the MVD is seeing an extensive and growing support and availability in BIM platforms available to users in all global markets.

4.1.11 IFC4.3 Base MVDs

In the lessons learned from the deployment of IFC2x3 and IFC4, there is yet another shift in strategy of IFC-based data exchanges from bSI where ***base MVDs***, that is MVDs that define a set of requirements common to many potential workflows, are being developed by bSI to ensure any IFC4.3-based data exchange workflows are interoperable across a wide range of software products as long as the MVD uses an official base MVD and the software has proven, certified support for such **base MVDs**. As the IFC4.3 schema documentation matures and the ISO approval process moves forward over the course of 2022-2023, this strategy of utilizing official **base MVDs** as the basis for IFC-based BIM-BEM exchanges will be expected.

4.2 Alternate Data Schemas and Exchange Methodologies

The bSI community must recognize the use of other non-proprietary methods to capture and exchange data for the purposes of BEM workflows. The following alternatives represent just a few, but more prominent, of resources available to use for BIM-BEM workflows.

4.2.1 Green Building XML (gbXML)

In 2000, the first version of a new, independent, XML-based schema describing the elements of a building was published by Green Building Studio, Inc. Rather than being a multi-purposed, multi-serialized schema like IFC, gbXML[39] was focused solely on exchanging information between BIM software platforms for building energy modeling and analysis processes. Since then, GBS, Inc., and its software Green Building Studio, was acquired by Autodesk (2008) and gbXML became an independent, open standard managed by its own public non-profit organization (2009). The gbXML organization, focused on BIM-to-BEM data exchange, with no small help from association to, and adoption by, Autodesk has propelled gbXML into the marketplace and use by industry. Support for gbXML-based exchanges can be

[37] See https://technical.buildingsmart.org/standards/ifc/mvd/mvd-database/ and https://standards.buildingsmart.org/MVD/RELEASE/IFC4/ADD2_TC1/RV1_2/HTML/

[38] See https://technical.buildingsmart.org/services/certification/ifc4-program/ and https://b-cert.org/

[39] See https://www.gbxml.org/index.html

found in over 50 BIM and BEM products[40], including a number of well-known market BIM authoring and CAD platforms, such as Autodesk Revit, Bentley OpenBuildings Designer, GRAPHISOFT Archicad, Trimble SketchUp, and McNeel Rhinoceros3D, as well as Autodesk's Insight, Bentley Hevacomp, EDSL Tas, IES Virtual Environment (IES-VE), and NREL Open Studio, to name a few. As such, gbXML can be seen as the primary competition to IFC in data exchange for the purposes of BIM-to-BEM.

Being an XML-based schema with particular focus on BEM, gbXML has some significant architectural and semantic differences from IFC[41], including a highly simplified geometric representation and "*a bottom-up approach, which is flexible, open source, and a relatively straight-forward data schema*."[42]

Past efforts have been made to reconcile, create mapping between, and provide conversion utilities between gbXML and IFC (ifcxml)[43], but there is continued interest in rallying around the use of IFC for BEM as a fully integrated process within openBIM enabled workflows and process. However, in any further buildingSMART community efforts, the relative success of gbXML should not be dismissed and consideration should be given to how gbXML may be incorporated into data exchanges, lessons that can be learned from the gbXML schema and implementations, and how IFC-based implementations can be improved, including changes to future versions of the schema.

4.2.2 CityGML and the Energy Application Domain Extensions (ADE)

CityGML[44] is another XML-based meta-format describing the built environment, primarily focused on metropolitan-level, and broader geographic region, urban context description. It is tended by the OGC and ISO Technical Committee 211 – Geographic Information/Geomatics (ISO/TC211)[45]. There are a variety of software applications and web-based platforms that support the use of CityGML, from commercial to FOSS (Free Open Source Software), in various use cases including viewing, mapping, geo databases, and translation between other formats.[46]

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[40] The gbXML Software list can be found at https://www.gbxml.org/Software_Tools_that_Support_GreenBuildingXML_gbXML.html

[41] See "A comparative study of the IFC and gbXML informational infrastructures for data exchange in computational design support environments" by B. Dong, K.P. Lam, Y.C. Huang, and G.M. Dobbs for the proceedings of Building Simulations 2007 Conference of the International Building Performance Simulation Association (IBPSA).

[42] B. Dong et al., "A comprehensive study of IFC and gbXML…"

[43] IFC-to-gbXML-converter by Maarten Visschers (see https://github.com/MGVisschers/IFC-to-gbXML-converter) and the 'bimServices' ""_fromGBxml.ifcxml.xsl" and ""_asGBxml.xml.xsl" from AEC3. See more at https://www.nibs.org/page/bsa_energie09.

[44] See https://www.ogc.org/standards/citygml

[45] See https://www.iso.org/committee/54904.html

[46] See the CityGML Wiki http://www.citygmlwiki.org/index.php

CityGML covers the geometrical, topological, and semantic aspects of 3D city models with a class taxonomy, distinguishing buildings from other man-made artefacts, vegetation objects, water bodies, and transportation facilities like streets and railways. Unique features of CityGML include[47]:

- Five consecutive Levels of Detail (LoD) and are used for efficient visualization and data analysis;
- Spatial properties of thematic objects are represented by a geometrical-topological model using Boundary Representation (B-REP);
- Real-world entities are represented by application objects, for example buildings, including attributes, relations, and aggregation hierarchies (part-whole-relations) between objects. On the spatial level, geometric-topological objects are assigned to semantic objects, which represent their spatial properties. Thus, the model consists of two hierarchies, the semantic and the geometric- topological, where the corresponding objects are linked by relations.

CityGML is meant as a ***generic*** standard for modelling topographic features, thus it is not always possible to store semantic information required by certain applications. Domain-specific information can be modelled in CityGML either by using/adapting the existing generic classes or by the definition of an ***extra formal schema*** based on the CityGML schema definitions. These schema *extras* are called "**Application Domain Extensions (ADE)**". This approach of formal schema extensibility makes it possible to define new classes, their relationships, and attributes, thus ideal for applications that require a large number of new features**.**

The objective of the Energy ADE is to store and manage data required for the building energy modelling, simulation and analysis workflows rooted in the CityGML-based virtual 3D city model.[48] The physical boundary of this specific domain extension is the building envelope, including the systems installed on it (e.g., solar panel, shading devices). Small-scale centralized energy systems may also be modelled in the Energy ADE. Following the philosophy of CityGML, the Energy ADE aims to be flexible, in terms of compatibility with different data qualities, levels of details and urban energy model. The Energy ADE can accommodate existing international building and energy data specifications, like the INSPIRE Directive of the European Parliament, as well as the recent US Building Energy Data Exchange Specification (BEDES).

As the OGC is a partner organization of buildingSMART International and co-member of several ISO Technical Committees and Working Groups, any bSI

[47] See http://www.citygmlwiki.org/index.php?title=CityGML_Energy_ADE_V._2.0

[48] See https://opengeospatialdata.springeropen.com/articles/10.1186/s40965-018-0042-y

community actions on Building Energy Modelling should take CityGML + Energy ADE into account as either a component to one of the needed exchanges, or as a reference to improve IFC-based exchanges through custom property requirements or edits to future schema versions.

4.2.3 BuildingSync® and BEDES

Another data capture and exchange effort has reached a high level of maturity, BuildingSync® <https://buildingsync.net/>, currently version 2.4.0, a large collaborative effort[49] managed by the National Renewable Energy Laboratory (NREL) a national laboratory of the U.S. Department of Energy (USDOE), Office of Energy Efficiency and Renewable Energy (EERE), and operated by the Alliance for Sustainable Energy, LLC. It is an XML-based schema with roots in gbXML and shared concepts from IFC.

From the website:

> *"BuildingSync® is a common schema for energy audit data that can be utilized by different software and databases involved in the energy audit process. It allows data to be more easily aggregated, compared, and exchanged between different databases and software tools. This streamlines the energy audit process, improving the value of the data, minimizing duplication of effort for subsequent audits, and facilitating achievement of greater energy efficiency.*

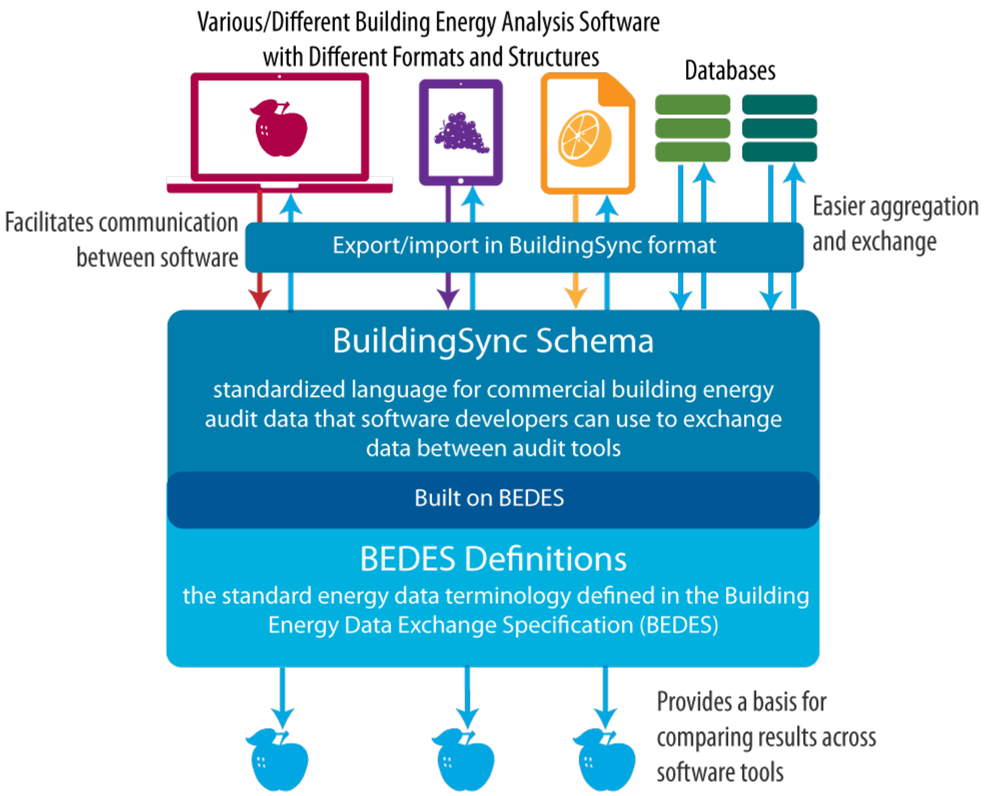

Figure 1: Diagram of BuildingSync / BEDES workflow

[49] See https:/

BuildingSync was developed to address the lack of an industry-standard collection format for energy audit data. Standardizing energy audit data can help energy auditors, software providers, building owners, utilities, and other entities by maximizing the value that can be obtained from each set of data - value obtained through collaboration, comparison, and reuse."

There is extensive schema documentation on the website, including a Data Dictionary, list of Measures, and detailed XSD description.

The [Building Energy Data Exchange Specification (BEDES)](), pronounced "beads" or /bi:ds/), is a data dictionary focused solely on building energy data, developed, and promoted alongside BuildingSync. It is intended to facilitate the exchange of building energy data between a plethora of applications and schemas/formats currently in use, including BEM use cases. As seen in Figure 1, BEDES is the foundation for the development of the BuildingSync schema as a means to exchange data.

4.2.4 Brick

In addition, the independent development of Brick <https://brickschema.org/>, a free, open-sourced ontology to *"standardize semantic descriptions of the physical, logical, and virtual assets in buildings and the relationships between them. Brick consists of an extensible dictionary of terms and concepts in and around buildings, a set of relationships for linking and composing concepts together, and a flexible data model permitting seamless integration of Brick with existing tools and databases. Through the use of powerful Semantic Web technology, Brick can describe the broad set of idiosyncratic and custom features, assets and subsystems found across the building stock in a consistent matter."*[50] It is promoted as a more robust alternative to IFC for the support of Sensor Systems, Control Relationships, and Operational Relationships, though this could be disputed.

Modeling Support	Brick	Project Haystack	IFC	BOT	SAREF
HVAC Systems	yes	yes	yes	no	no
Lighting Systems	yes	partial	yes	no	no
Electrical Systems	yes	yes	yes	no	no
Spatial Information	yes	no	yes	yes	no
Sensor Systems	yes	yes	generic	no	yes
Control Relationships	yes	no	generic	no	no
Operational Relationships	yes	no	generic	no	no
Formal Definitions	yes	no	yes	yes	yes

Table 2: Comparison table of semantic schemas from the Brick website

[50] Per https://brickschema.org/

It appears that implementation/adoption of BuildingSync, BEDES, and Brick is quite nascent in the USA BEM community/industry, but it provides an interesting insight into alternate structured data models for BEM, as well as potential for linked data scenarios, where data in the format of one schema may be transformed into another for appropriate end uses.

4.2.5 ASHRAE Standard 223P (Proposed)

In the USA, the US Department of Energy (USDOE)[51], has many laboratories and concurrent projects which address energy efficiency, including design, simulation and analysis, and data capture and exchange. It is well-known internationally for the development of DOE-2 <https://www.doe2.com/> and EnergyPlus <https://energyplus.net/>, whole building energy simulation software applications used to model energy consumption of buildings. For many years, these products and other work by the USDOE were considered the ‘state of the art’ for BEM and used both inside and outside the US. In the last 10 years, the USDOE has expanded is research and work to include more data schema, exchange, and dictionary efforts as disclosed below.

The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE)[52] is an international icon for the advancement of “*the arts and sciences of heating, ventilation, air conditioning, refrigeration and their allied fields.*” Many of the USA standards (and influences for international standards) for the design / engineering and performance of buildings, systems, and components[53] are governed by ASHRAE. USDOE tools typically are calibrated to ASHRAE standards and include libraries of performance specifications for use in the development, simulation, and analysis of BEMs.

In 2018, the USDOE EERE and ASHRAE announced a new research initiative, ASHRAE Standard 229P, to develop a new “*… standard that aims to improve accuracy, consistency, and outcome predictability in projects using ruleset-based performance calculations.”*[54] That effort initially proposed[55] the development of automated rulesets, and open source checking tool, to compare a design model against a baseline model in software, by providing a dictionary of standardized, uniform semantic tags to describe the necessary BIM data structures for BEM implementations using BIM data. However, as further work was explored on the project by associated ASHRAE working groups, the effort has been reframed[56] as a

[51] See https://www.energy.gov/

[52] See https://www.ashrae.org/

[53] See Appendix B - Building Energy Efficiency Standards / Protocols

[54] See https://www.energy.gov/eere/buildings/ashrae-standard-229p-development

[55] See https://www.energy.gov/sites/default/files/2021-10/bto-peer-2021-evaluating-ruleset-implementations-modeling.pdf

[56] See https://haystackconnect.org/wp-content/uploads/2019/05/Proposed-ASHRAE-Standard-223P-Bernhard-Isler.pdf and https://www.ashrae.org/about/news/2018/ashrae-s-bacnet-committee-project-haystack-and-brick-

"… *linked data information model defining concepts and requirements for describing automation systems to promote semantic interoperability.*" by creating a "Building Automation Systems Information Model (BAS-IM) in conjunction with BACnet® <http://www.bacnet.org/>, Project Haystack <https://project-haystack.org/> , and Brick (see above).

ASHRAE 223P may provide a novel solution for general BIM-BEM interoperability or may be another means to connect/link relevant information according to specific uses cases. The concept of linked data interoperability in buildingSMART has been building for some years and seen fruition in the buildingSMART Data Dictionary (bSDD) and the exploration of serializing IFC-based BIM data using JavaScript Object Notation (JSON). ASHRAE 223P may be another schema to interpret data from one BIM node using an IFC context to a BEM node leveraging the 223P context.

4.3 Further International Research Efforts

Of course, the subject matter of BEM and the optimal collection and usage of information from various sources in increasingly digital ways of working, such as BIM, has been happening for many years and by many organizations around the globe. As such, this section

4.3.1 European Commission Horizon 2020 (H2020) BEM Projects

Horizon 2020[57] is a European Union framework programme for research and innovation where funding collected from EU member states is aggregated and then granted to a multitude of projects satisfying the general objective "*to build a society and a world-leading economy based on knowledge and innovation across the whole Union, while contributing to sustainable development.*" There are a great number of programmes (topic-specific research/funding agendas) that have been funded over the last ten years which address sustainability, energy efficiency, BIM, and BEM at many different scales and across many different sub-topics. This includes but is not limited to:

- LC-EEB-02-2018: Building information modelling adapted to efficient renovation (RIA)[58]. Related projects and proposals can be found at https://cordis.europa.eu/search?q=contenttype%3D%27project%27%20AND%20programme%2Fcode%3D%27LC-EEB-02-2018%27&p=1&num=10&srt=/project/contentUpdateDate:decreasing

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schema-collaborating-to-provide-unified-data-semantic-modeling-solution and https://www.ashrae.org/news/esociety/ashrae-bacnet-committee-works-with-other-organizations-on-new-standard

[57] See https://cordis.europa.eu/programme/id/H2020-EC

[58] See https://cordis.europa.eu/programme/id/H2020_LC-EEB-02-2018

- EU-3.3: SOCIETAL CHALLENGES – Secure, clean, and energy efficient. Related projects and proposals can be found at https://cordis.europa.eu/search?q=contenttype%3D%27project%27%20AND%20(programme%2Fcode%3D%27H2020-EU.3.3.%27)%20AND%20(%27BIM%27)&p=1&num=10&srt=Relevance:decreasing

- EU-2.1.5.2: Technology enabling energy-efficient systems and energy-efficient buildings with a low environmental impact. Related projects and proposals can be found at https://cordis.europa.eu/search?q=contenttype%3D%27project%27%20AND%20programme%2Fcode%3D%27H2020-EU.2.1.5.2.%27&p=1&num=10&srt=/project/contentUpdateDate:decreasing

Specific examples include:

- H2020 OptEEmAL (H2020-EU.2.1.5.2 / EeB-05-2015)[59] – Research into the development of an "Optimized Energy Efficient Design Platform for Refurbishment at District Level".

- H2020 swimming (H2020-EU.2.1.5.2 / EeB-04-2014)[60] – Research into the development of "Semantic Web for Information Management in Energy Efficient Buildings".

Given the breadth and variety of potential sources of information and inspiration for data exchange methodologies and standards, Subject Matter Experts (SMEs) in the buildingSMART and BEM communities who have direct experience in and knowledge of the H2020 programme should be engaged to determine which projects might be best suited for reference to the BIM-BEM data exchange challenge.

4.3.2 International Energy Agency (IEA) and the International Building Performance Simulation Association (IBPSA) Annex 60 / Project 1

In 2012, the IEA commenced with a project within the Energy in Buildings and Communities Programme to *"…develop and demonstrate next-generation computational tools that allow building and community energy grids to be designed and operated as integrated, robust, performance-based systems."* The project, known as IEA EBC Annex 60 (2012-2017)[61], and later continued as IBPSA Project 1 (2017-2022)[62], is focused on the use of Modelica[63] for modelling the performance of building and district energy systems while consuming data models via IFC and

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[59] See https://cordis.europa.eu/project/id/680676

[60] See https://cordis.europa.eu/project/id/637162

[61] See http://iea-annex60.org/

[62] See https://ibpsa.github.io/project1/

[63] See https://modelica.org/ and Appendix C

CityGML. The intent to is leverage existing international data standards and open-source software to remove proprietary system barriers, lowering the threshold for implementation across the industry, and create an opportunity for consistency between micro- and macro-scale simulation and analysis.

4.4 Other Academic and Industry Research References

Beyond the previous efforts, there have been a great number of academic and industry research projects and papers published which address the many issues of, as well as various approaches to, BEM. The report includes references to a modest number of these studies. See **Appendix A – Academic and Industry Research References**. Some copies of such documentation may be found as part of this report’s file library in the “Research_References” folder. The appendix documents these studies as well as others that should be considered in the further development of IDMs for each possible data exchange.

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5 Building Energy Modeling (BEM) Lifecycle Overview

In the general model-based project delivery and operations workflow, there are numerous potential touch points for model information to be used for BEM. Where and when each of these potential analyses occur, and how the necessary information is gathered or exchanged, may also depend on the adopted standards or best practices for a particular market/nation.

5.1 Plans of Work – Phasing/Staging Project Delivery

Generalized project delivery standards are typically expressed by national or international classification systems and/or formalized contract processes and language (aka *Plans of Work*). Examples include, but are not limited to:

- **Germany – HOAI Leistungphasen 1-9** https://www.hoai.de/hoai/leistungsphasen/
- **International - buildingSMART International (bSI) Information Delivery Manual (IDM) Project Stages** https://standards.buildingsmart.org/documents/IDM/IDM_guide-CompsAndDevMethods-IDMC_004-v1_2.pdf
- **International – Construction Specification Institute (CSI) OmniClass Classification System Table 31 – Phases** https://www.csiresources.org/standards/omniclass/standards-omniclass-about
- **UK – Royal Institute of British Architects (RIBA) Plan of Work 2020 Stages** https://www.architecture.com/knowledge-and-resources/resources-landing-page/riba-plan-of-work
- **USA – American Institute of Architects (AIA) Integrated Project Delivery: A Guide** https://help.aiacontracts.org/public/wp-content/uploads/2020/03/IPD_Guide.pdf#_ga=2.181235118.888998490.1643694100-1133995384.1643694100

These *plans of work* typically break the project delivery process into different stages or general phases including:

- **Pre-Design**, where project requirements and important context information are gathered prior to design work;
- **Design**, where multiple disciplines work to provide design intent documentation for the various use, aesthetic, structural, and performance requirements;
- **Construction**, where the design documentation is used to tender/bid, procure, and build the project;

- **Operations & Maintenance**, where the owner/operator takes control of the project and puts it into use;
- **Re- or Decommissioning**, where a project and/or its systems may be retrofit or refurbished to limited or extensive degrees OR completely removed from service, demolished, or deconstructed.

Some plans of work may provide more subdivisions, each of which have a narrower focus, like separating Tendering/Bidding or Permitting from Construction or delimiting various Design stages like Feasibility Study, Schematic Design, Design Development, and Construction Documentation, as examples. Many of these systems have deep histories tied to traditional design and construction methods but may have been updated as the industry slowly moves to embrace digitally based practices. While these formal systems may vary greatly in their detail, all have the same intent to standardize and document the project delivery processes to insure regularity between projects and hope for high-quality outcomes in following set procedures.

Any given project may have requirements or overall expectations that require some, if not all, of the possible types of BEM analyses identified in this document. In this section, we consider the general phases of a project lifecycle and the opportunities for different types of building energy modelling uses to occur within those phases, the stakeholders involved, the general information requirements, and the possible standards/protocols available to guide the building energy modeling and analysis process. Documenting such requirements can help determine what information can be derived or sourced from where and what form it may take.

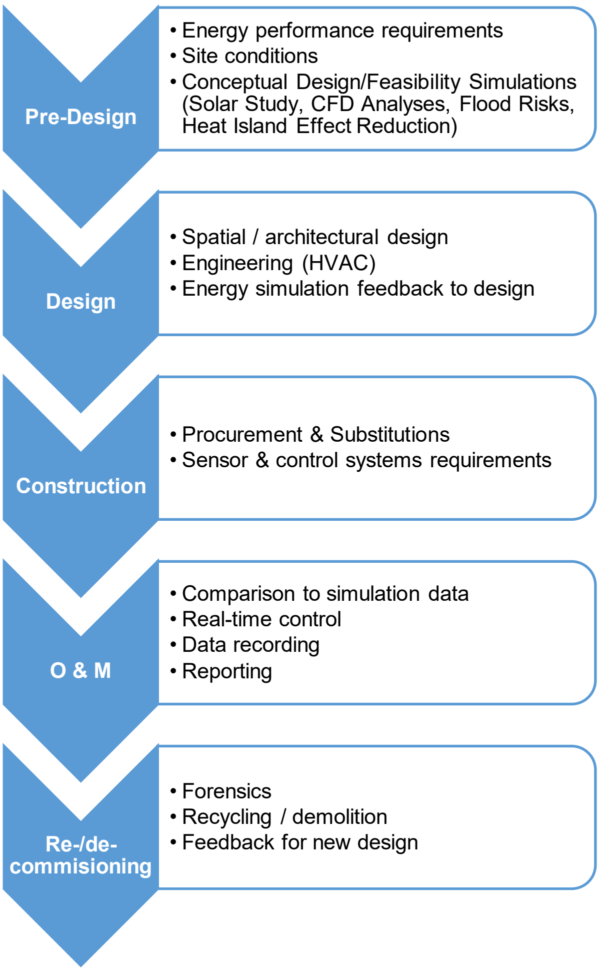
For this report, the emphasis is on how a model-based (BIM) project delivery methodology can provide needed data to execute building energy modeling, simulation, and analysis, as well as potential for BEM results to inform or directly affect other BIM (model-based) workflows, including operations and maintenance along with design and construction.

The term ***energy model*** is used in the generic sense. There is no prescription for a particular BEM technology or methodology, at any stage, like there is none for BIM. The many opportunities to leverage BEM workflows may involve one evolving model or multiple models of differing complexity and detail. As learned during the evolution of BIM in the industry, there is also no one tool or method to achieve good, desired results. However, there is a need to accommodate such variety by liberating the needed information from the tools and providing open, standardized ways of sharing that data in a meaningful way for the tools/technology and the posterity of the project and its stakeholders.

5.2 General Phase Summaries

For the purposes of this report, we will be summarizing the lifecycle phases in highly general terms of **1) Pre-Design, 2) Design, 3) Construction, 4) Operations &**

Maintenance, and 5) Recommissioning / Decommissioning. Figure 2 shows how these 5 generalized phases compare to the bSI IDM Project Phases. For any prescribed project delivery process standard, as mentioned in Section 5.1 Plans of Work, similar comparison or mapping could be done to adapt proposed data exchange specifications to standardized national or international project delivery phases.



bSI IDM Project Phases

0. **Portfolio Requirements** – applicable codes and standards, owner requirements (energy use targets), possible financial incentives, etc.
1. **Conception of Need** – Functional requirements / spatial programming
2. **Outline Feasibility** – Massing Model design analysis (site and general info, simple 3D geometry, rules of thumb [loads, thermal transfer, etc.])
3. **Substantive Feasibility** – Concept development to initiate contract/financial execution
4. **Outline Conceptual Design** – Initial Design Development (generic systems, assemblies, cladding materials, important finishes)
5. **Full Conceptual Design** – Final Design Development (complex geometry, materials, constructions, systems, etc.)
6. **Coordinated Design and procurement** – Procurement & Substitutions
7. **Production Information** – Procurement & Substitutions
8. **Construction** – Procurement, Substitutions, Installation, and Commissioning
9. **Operations and Maintenance** – Commissioning and Occupancy
10. **Disposal** – Post-occupancy forensics (lifecycle analysis of design vs. actual behavior)

Figure 2: A generalized Building Energy Modelling Life-cycle Overview alongside the official bSI IDM Project Phase nomenclature.

The following high-level summaries will identify opportunities for information to be leveraged in model-based and BEM workflows at each general phase. They are not meant to be prescriptive or exhaustive, but observational and general enough to allow flexibility in where and how BEM strategies may fit with the other model-based design, procurement, construction, and operational processes throughout a project's lifecycle. The Exchange Models in section 6: Proposed BIM-to-BEM Project Lifecycle Data Exchanges will suggest more detail in potential processes, workflows, and information requirements

5.2.1 Pre-Design

Pre-design activities are focused on the documentation of portfolio / performance / use requirements that will drive all the subsequent design and BEM activities. This can include local building code requirements for energy performance, owner expectations, regional energy supply sourcing and rates, and any financial incentives for meeting certain performance targets.

The primary use of building information modeling at this point may be to document site conditions at macro (e.g., regional, district, campus) and/or micro (site boundaries) levels. Such models might include existing natural context (e.g., terrain/topography, vegetation, bodies of water, geotechnical, etc.) as well as man-made (e.g., existing buildings on and adjacent to site, roads, utilities, etc.). Such context can provide for initial building energy modeling microclimate analyses (e.g., natural airflow patterns via CFD analysis, sunlighting/sun path studies, heat island simulations, etc.).

For recommissioning and historical preservation projects, where an existing building would undergo retrofitting/refurbishment in whole or selected parts, additional requirements for such work would be determined, as well as the processing of forensic analysis of present/previous conditions to determine the state of the building prior to interventions being designed and applied.

5.2.2 Design

Design activities range from initial conceptual design – including low resolution physical feasibility and more abstract economic studies – to fully detailed construction intent models and documentation of all building fabric, structure, and systems used in the following Construction and Commissioning phase. The bulk of BIM processes and workflows take place in the Design phase, generating models of increasing complexity over time, as the building design comes into focus, usually with a lot of reiterative effort of design, review, feedback, and revision.

Here BEM can be seen as an integral part of the design process, providing valuable input into and insight about architectural design and building services system (mechanical, electrical, plumbing) proposals, as well as feedback on their efficacy in meeting project requirements. Like the building information models developed by the other disciplines, building energy models will also vary in complexity – usually in increasing levels of geometric and information richness – over the Design phase, with many opportunities for data to be shared from various BIM data sets and even BEM data integrated back into the BIM process models at various stages.

5.2.3 Construction and Commissioning

During construction, valuable aspects of a model-based project delivery method is in the quantification, pricing, construction logistics modeling, and material supply logistics of the construction process. Here the potential added value of BEM is in determining if substitutions proposed during the tendering and procurement processes will be expected to provide suitable performance. Often during tendering and construction, design targets may need to be adjusted, or gaps identified and remediated. During procurement, materials may be unavailable or unsuitable and corresponding construction details may need to be changed. In some cases, entire systems may need to be substituted. These changes may dramatically affect energy performance. By using BEM, the effect of the proposed changes on energy performance can be calculated. In addition, future operations and maintenance processes involving building systems monitoring and controls can benefit from BEM integrations to determine the best means of setting up and operating such systems.

During commissioning and handover to the owner/operator, the BIM-based project delivery process sees models reflecting as-built conditions, where the results of procurement and installation are ultimately recorded to provide an as-built record. With such information, BEM simulation and analysis can be used to assist the tuning of building systems for optimal performance, as well as their monitoring and controls.

5.2.4 Operations & Maintenance (O & M)

Post-construction, a complete, as-built, and data-rich building information model provides owners/operators with a basis to understand the building in a much deeper way than from 2D drawings and equipment manuals. With such a model, the value of a model-based project delivery can be extended into a ***Digital Twin*** context, tying the model into real time control and monitoring systems during the building’s lifecycle. Again, there are opportunities for BEM simulation and analysis to be used to help meet data recording and reporting requirements, as well as projecting future performance based on combining real-time feedback of building systems operations with energy supply rates and expected heating and cooling conditions (such as forecasted weather or occupant use schedules). Gaps between designed performance values and actual operating conditions can be identified and strategies for mitigations determined.

5.2.5 Recommissioning / Decommissioning

When the end of the useful lifecycle of a facility has been determined, either due to economics or degradation in physical state or performance, it goes through a process where it may be retrofit or refurbished (recommissioning), in parts or in whole, or completely taken out of service and demolished (decommissioning). In the case of recommissioning, a forensic analysis of performance data collected during the facility’s lifecycle can help designers and consultants determine the worst and best performing components and system in evaluating the extents of leaving assets in place, replacing one-to-one, or removing and upgrading them with more efficient ones.

A significant asset of this process is the as-built model, where all existing physical conditions are captured as well as the operational data possibly collected over the facility’s use. For BIM-based projects, this model may be a product of the phases summarized previously. For existing buildings, including those of a historical designation, it may be necessary to generate an as-built model from various surveying methods. At this point, the Recommissioning phase of an existing building blends with the Pre-Design phase of the next iteration or rebirth of a building where project requirements for a new future state are combined/compared with existing physical conditions and historical performance data.

5.3 Stakeholders / Participants / Disciplines / Roles

In a building project, there are a wide variety of potential stakeholders/participants who will be providing or consuming data. Depending on the project, different participants may have different roles or responsibilities. Some highly specialized roles may be aggregated or distinct third-party consultants. For example, the Architect in one project may be responsible for providing typical formal geometry and spatial configurations with basic construction information (e.g., materials, systems) which the Building Services Engineer and Building Energy Consultant (aka Energy Services Company) review and respond with simulation and analysis-driven alterations, while in another project the Architect may also be the Building Energy Consultant and authority, providing the more exacting performance specifications themselves. In this section, we will provide a general summary of stakeholders, as well as more specialized roles, along with potential responsibilities with respect to building information modeling and/or BEM.

What about the occupants?

Typically, the occupants of the building will not have a direct say or influence on the execution of a project. Most occupant concerns are represented by many of the other roles, such as the Architect, Owner, or Operator, but also by such mechanisms as Building Codes and Building Energy Standards / Protocols which address building performance in the light of standards or expectations of human comfort. This includes occupants' comfort (thermal, visual, and acoustic) and Indoor Environmental Quality (CO2, radon, and other airborne particulates) as major factors that highly affect the energy consumption of a building. After all, the primary purpose of most buildings is to provide a place for humans to carry out a set of prescribed or intended activities. Their presence in the building has a direct effect on the performance of the building systems as much as the building acts as a machine to provide a comfortable environment in which to conduct the activities.

5.3.1 Architect

The Architect is a licensed professional in the project design and delivery process. They are responsible for providing the general design concept information of the project with formal geometries, spatial organization & functional programming. They may also be responsible for providing material selection and properties, and construction systems that follow their design concept and owner requirements. The Architect is also responsible for the health, welfare, and safety of a design, ensuring that all due care is taken, and all codes and regulations are followed to provide a safe and secure environment for users.

5.3.2 Building Services Engineers

The Building Services Engineers, aka ‘MEP Engineers’, are licensed professionals in the project design and deliver process. This includes Mechanical, or HVAC, Engineers for heating and cooling systems, of many variations in configurations, along with Electrical Engineers responsible for power distribution, communications, and lighting design, as well as Plumbing Engineers for water and waste-water systems, all working together in providing comfort to occupants and optimal design performance. All such engineering sub-specialties have an impact on building energy performance, as these systems are often highly integrated and can weight their impact more heavily on a design, through dependent system type (e.g., heat pump/exchange, radiant, forced air, PV, daylighting, grey/recycled water, etc.) and fuel source (e.g., solar, geothermal, electrical, fuel cell, etc.). The design of these systems often involves a reiterative process, through a dialog with the Architect and Building Energy / Sustainable Design Consultant, to balance optimal performance with owner requirements and cost constraints.

5.3.3 Lighting Designer

With the increased pressure on better building performance and providing optimal comfort and utility for occupants, the Lighting Designer is focused narrowly on daylighting and artificial lighting strategies, components, and systems. In larger, more complex projects, their unique focused expertise is helpful in finding the best design strategies, formal options, and product selection in balancing energy use, optimal lighting for multiple uses, and operational endurance and costs.

5.3.4 Building Energy / Sustainable Design Consultant or Energy Services Company (ESCo)

A Building Energy / Sustainable Design Consultant, in some cases also known as an Energy Services Company (ESCo) is a specialist in providing performance best practices and energy efficiency knowledge for a building/project. They will provide input and feedback to decision makers on design options, but in general will not directly approve or reject designs. Commonly, these consultants will have access to tools, methods, and information specifically applied to a building type and location, or jurisdiction, for the appropriate simulation and analysis.

Their work may also include advice on energy conservation methods, retrofitting, power generation/supply and distribution, project resilience/risk management, among a broad variety of energy-related and building performance topics. The role and responsibilities of the BE Consultant has also been formalized in EN 16247-5 *(Energy Audits - Part 5: Competence of Energy Auditors)*[64] as the Energy Auditor.

5.3.5 General Contractor / Constructor / Construction Manager

The General Contractor (GC), aka Constructor, is the senior person or team responsible for the procurement of materials and erection of a building or facility. They will typically oversee a variety of subcontractors and trades. In this context, they represent the individuals or groups who are responsible for the construction side of any design alterations during the procurement and construction processes. In some cases, the GC may be directed by a third-party Construction Manager (CM), contracted by the owner to direct and oversee the procurement and construction process. This may take the burden of some overall project administration and responsibilities from the GC, allowing them to focus more intently on construction and allow the CM to take higher-level actions and responsibilities when coordinating any changes with the other stakeholders.

5.3.6 Building Product Manufacturers & Suppliers

The Building Product Manufacturers & Suppliers are companies or independent representatives who provide the various materials, components, and systems for the project which also affect the energy performance efficiency of a building. This may also include independent entities that provide BIM/BEM data and files of those materials, components, and systems, at the behest of product manufacturers and suppliers. The manufacturers and suppliers will be the trusted, definitive source for most, if not all, the performance characteristics of materials, components, and systems which the Architect, Building Services Engineers, and Building Energy Consultant will use in their BIM generation, as well as BEM simulations and analyses. During the procurement and construction phases, they will also be directly interacting with the GC and/or CM.

5.3.7 Commissioning Agent

The Commissioning Agent (CA) is responsible for the process in which installed systems (e.g., lighting, plumbing, HVAC, power generation, etc.) are confirmed to be working correctly and if necessary, tuned to meet the designed performance expectations.

5.3.8 Owner

The Owner is the ultimate decision maker for the building. They provide performance targets, budgets, and approve all design decisions based on input from the other contracted stakeholders.

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[64] See https://www.en-standard.eu/bs-en-16247-5-2015-energy-audits-competence-of-energy-auditors/

5.3.9 Operator

The Operator has responsibility and decision-making authority for the daily operations of a building, and in general is responsible for daily operational costs. The Operator will have insights into the suggested design alternatives to balance upfront costs with long term operational cost including the materials and labor needed to maintain and replace installed components and systems. The Operator will usually have the responsibility to deploy and maintain any computer-assisted maintenance and monitoring & controls systems as much as the general maintenance and operations of the building as a whole.

5.3.10 Regulating Authority

The Regulating Authority, aka *Authority Having Jurisdiction* (AHJ), may be a singular entity (e.g., a municipal Building Permitting Department) or involve multiple entities (e.g., additional Planning & Zoning Commission, Utility Services, Environmental Review Board, etc.). In jurisdictions where there is an energy performance component of building permitting and approval, the local regulating authority may have a role in information exchange. While they will not be conducting any modelling or first-hand analyses in the pre-design and design stages, they may be providing up front information on energy code requirements. Prior to construction, the regulating authority will also provide approvals, based on the results of third-party or internal building energy model simulation and analysis. In some jurisdictions, regulating authorities (or quasi-regulating authorities) may also provide post construction certification based on actual performance results in combination with the prior BEM simulations and analyses.

5.3.11 Building Performance Certification Bodies

Appendix B – Building Energy Efficiency Standards / Protocols provides an extensive list of common building energy performance standards and certification protocols, as well as their governing authorities, used throughout the world. While all address building energy performance and overall sustainability of buildings over their lifecycle, they vary in many different ways including, but not limited to:

- application to a particular regional, national, or broader international scope;
- application of life cycle scope, where determination may be based on actual performance rather than designed intent and immediate built result;
- building use type, construction type, and/or scale;
- public or private ownership;
- integration with other contexts beyond the building envelope (e.g., public transportation, energy sourcing, regional climate, etc.)

5.3.12 BIM Manager / Coordinator

Throughout the entire BIM-based project delivery process, there is often a need for a role dedicated to ensuring that models and model-based information is properly managed according to a formal (or informal) project execution plan. In most circumstance, the BIM Manager/Coordinator acts as the hub for all data exchanges and possible data transformations needed for various uses. They are the expert in the flow of needed information, as well as the location and state of it at any given time. They are essentially part of every data exchange transaction, either directly or directly, in setting up the standards and protocols for the entire project delivery team to share information, to being the middle-man for receiving, quality-checking or validating data sets being exchanged, to troubleshooting problematic exchanges, which were assumed to meet the expectations of a project execution plan with data and information handling standards, but may have some kind of error for the author or recipient.

5.4 General Information Requirements

In order to carry out any BEM at any project lifecycle stage, there are a number of information requirements needed for input into any of the BEM methodologies and software platforms. The gathering of this information is not always straightforward, as the data may need to be aggregated from many different sources, types, and formats and each of the exchanges may have similar information type requirements as other exchanges but require different levels of detail or complexity. It is imperative to find the right balance of information quantity, as well as quality and/or detail, to establish the *best common denominator* of information requirements needed to optimally satisfy each exchange.

5.4.1 LOX / LOIN

An overarching factor to all information requirements, including data/information creation, collection, and transfer, is the scope and detail possible to use for an identified purpose or process. With current BIM authoring tools, it is relatively easy to create a nearly infinite amount of geometric detail and associated data points for models of any size or scale. LOX is an acronym meant to generally represent various “Levels Of X”, where ‘X’ may be ‘detail’, ‘development’, ‘information’, or other information modelling or management concepts. This concept is also represented using the acronym LOIN, meaning “Level Of Information Need”. The LOX/LOIN may be applicable to both physical and analytical / abstract information.

An example of a LOX guide is the BIMForum / NBIMS-US LOD Specification[65], which prescribes the best level of information needed for the identified purpose and thus supply no more, or no less than, in scope and detail for a stage in a project delivery process. LOIN has been introduced in the ISO 19650-1 *(Organization and digitization*

[65] See https://www.nationalbimstandard.org or https://bimforum.org/lod/

of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 1: Concepts and principles) standard[66] and further defined in EN 17412 *(Building Information Modelling - Level of Information Need - Part 1: Concepts and principles)*[67].

A LOX/LOIN that is too high for a given purpose or exchange may put undue burden on the stakeholder responsible for supplying or collecting the information and then see much of that collected information wasted, or not used, in the process or use. A LOX/LOIN that is too 'low' might not provide sufficient data for a proper analysis at a given stage or use.

5.4.2 Performance Requirements

Performance requirements include the following information used to set up the basis for the application of BEM on a project:

- **Building codes and BEM standards / protocols**, such as the International Building Code (IBC) and the Leadership in Energy and Environmental Design (LEED), which provide constraints for construction types, quality, and use of materials, energy efficiency baselines for equipment and appliances, and reducing CO2 emissions, as well as larger trending goals of global net-zero carbon emissions[68];
- **Planning and zoning regulations,** which provide formal constraints on development types, uses, construction, and sizes/scales;
- **Economic development incentives**, such as municipal rebates on permits, property tax abatements, or a percentage of costs for energy efficiency refurbishment of existing buildings, which may add incentives for the building owner/developer to pursue a particular strategy in the project's performance;
- **Life Cycle Cost (LCC) and other Return-On-Investment (ROI) factors**, such as energy-efficient equipment and material premiums, embedded carbon offsets, supply chain efficiencies, electrical energy and fossil fuel delivery costs, and prevailing market rental rates or capital lending rates, which will further impact the owner/developer's decision-making process on the best strategy for capturing value in implementing building performance goals.
- **Owner or appointing party requirements and/or goals**, where the developing party may have specific achievements that are neither prescribed by code/regulation nor economically incentivized.

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[66] See https://www.iso.org/standard/68078.html

[67] See https://www.en-standard.eu/din-en-17412-1-building-information-modelling-level-of-information-need-part-1-concepts-and-principles/

[68] See https://netzeroclimate.org/what-is-net-zero/

5.4.3 Site

The site information requirements include abstract and physical conditions of the particular site and its context. While the scale or breadth of the information varies from the small (e.g., a particular site or lot) to the large (e.g., a long-distance region for an entire city or linear infrastructure project, it is not necessarily deeply or highly detailed). These requirements include:

- **Geolocation and Geography**, providing exact location and site boundary geometries (lot lines, setbacks, etc.), as well as including surface conditions of the land (contours) and sub-surface geotechnical strata. Geographic Information System (GIS) data can vary in detail and accuracy since surveying information is done with widely varied methods (e.g., aerial, satellite, manual surveying, etc.) and combined. Drone (photogrammetry) and satellite imagery may also be considered.

  Formats include GML, LandXML, DWG (2D/3D), Esri Shapefiles (SHP, DBF, SHX, LYR), GeoJSON/JSON, KML/KMZ, OSM. However, there is an increasing use of point cloud data, in the form of XYZ, LAS, PCD, and E57. Satellite and drone photogrammetry image data may be via Landsat, Pleiades, or Sentinel formats directly or transformed into orthophotos via JPEG/JPG, PNG, TIFF, or GeoTIFF;

- **Context (natural and built)**. In addition to the geolocation and geographic data, there may be natural and/or man-made features, such as water bodies and/or containment structures, trees and other vegetation, and adjacent buildings/structures, as well as surface and sub-surface infrastructure (e.g., roads, rail, utilities).

  Formats are same as GIS data, usually uniquely identified subsets of the same GIS dataset delineated as *layers*;

- **Climate / weather data**, which can come in two types of datasets either a Typical Meteorological Years (TMY) set which includes the means, averages, highs and lows of measures over a number of years, OR a single-year set, also known as an Actual Meteorological Year (AMY). Most simulations rely on the multi-year averaging, though recent climate change related anomalies have experts using more recently compiled yearly data with more extreme measured values. Recent developments in the use of machine learning (ML) and artificial intelligence (AI) are also increasing the sophistication of software to leverage AMY data, or even forecasting data, and reported data on precedent building usage behaviour.

  Format is typically an EnergyPlus Weather data file (EPW). See http://climate.onebuilding.org for more information.

- **Demographic data**, from such sources as Eurostat[69] or the US Census Bureau[70], can sometimes be informative to the BEM process, through analysis of social trends that have physical impacts (e.g., traffic/road patterns, construction/impervious cover, construction/energy use and delivery, etc.).

  Formats can be the same as GIS data, usually uniquely identified subsets of the same GIS dataset delineated as *layers*, in distinct SHP or LYR files;

- **Energy sourcing survey**, which identifies the source and delivery of energy used by the building, such as the fuel type (e.g., nuclear, coal, natural gas, solar, biogas, etc.), location of the source (e.g., regional power plant, microgrid, district system, etc.), business model (e.g.,, public or private utility or self-generated), and transmission (e.g., transmission lines above or below ground, routes, power capacities, peak power schedules, etc.).

5.4.4 Building

Of course, at the core of BEM is the representation of the building and all the physical and abstract information that completes a view of the building from a performance perspective. That information can be expressed in analogous ***physical*** data sets (also known as Building Information Models, BIMs), including building elements, their geometries, materials, and material properties, as well as more abstract ***analytical*** data like occupant psychometrics, which act as constraints, or parameters, for simulations and resulting analyses to have their results judged.

5.4.4.1 Physical

Physical information, usually geometric representations of building elements (e.g., walls, doors/windows, slabs, ducts, lighting fixtures, etc.) and systems (e.g., lighting, HVAC, water supply & waste, etc.) can vary in levels of geometric detail, as well as information detail (also known as 'LOX'). Each workflow, or exchange, may have different limits or requirements to these levels based on the complexity of the modelling, simulation, and analysis according to such factors as design certainty/completeness, scale, formal complexity, and modularization/standardization.

- **Building elements** are generally understood as objects or composite constructions such as columns, walls, floors/slabs, windows, doors, etc. Spaces are a common but unusual case in that they are not a physical object themselves but can be depicted as digital objects with geometric extents (height, length, width, volume), attributes, and properties;

- **Materials and construction systems** include singular, homogenous materials such as steel, wood, concrete with varying identification of grades,

[69] See https://ec.europa.eu/eurostat/data/database

[70] See https://www.census.gov/programs-surveys/ces/data/restricted-use-data/demographic-data.html

as well as the compositing, or layering, of these materials to form structural and non-structural systems for building support, enclosure of spaces, and cladding of a building;

- **Fenestration** includes openings in construction systems (e.g., walls) that may or may not be 'filled' with windows, glazing systems, or doors that vary in type and material. These fenestrations will have an impact on the performance of the walls/slabs/roofs they are inserted into, the rooms they are related to, and overall building performance. They may be part of natural ventilation strategies in manual or automated modes of control;

- **Indoor Climate Control systems** include a variety of passive and active types (e.g., radiant, forced air, etc.), with varying degrees of technical and mechanical complexity for controlling indoor temperature (heating and/or cooling) as well as humidity and optionally, air quality. **Fuel types** are directly related to the operation of Indoor Climate Control systems, usually through combustion, electrified, or electro-mechanical systems, where fossil fuels (e.g., oil, natural gas, coal) or renewable-based sources (e.g., solar, geothermal, hydro, wind, etc.) are used;

- **Lighting systems** include electrical systems and natural daylighting schemas (including shading devices/elements) which have an impact on heat gain and subsequent building thermal performance, as much as energy consumption;

- **Controls and Sensors** are typically part of the Indoor Climate Control and Lighting systems but can be a distinct package in design and project delivery when their level of complexity rises and includes highly automated methods (e.g., computer-controlled, computer-monitored, motion-based switching, occupancy detection, and weather-linked methods for thermostats, switches/dimmers, etc.).

For all of these physical information features, there are a number of factors which complicate the need and extents of requirements for each exchange. Not all tools, not all processes, not all simulations, require, or can use, the same physical representations. The options for depictions of such physical aspects include:

- **Geometric representation types** – Modelling and model-based simulation tools may have differing abilities on geometry, such as being able to create or read constructive solids geometry (CSGs) or *simplified* surfaced-based geometries, or boundary representation (BREPs) such as NURBS, meshes, and tessellations. What is capable or appropriate for one tool and workflow may not be for another or all. This also includes issues of rendering, based on color and/or texture, for visualization or abstract representation purposes;

- **Scope of Modeled Elements** – Most often overlooked is the differences in actual geometry used by different methodologies and tools for BEM. Most exchanges to date have assumed that the analysis tools want, need, or can consume an entire building model with construction details like wall and slab material layers and detailed window/door construction. But some methods only require simplified analytical geometries (usually Space Boundaries of 1st and/or 2nd level) with thermal data from such "real" elements attached to them. And in some cases, there is a distinction and preference for either or both 'Net' and 'Gross' sets of analytical geometry. Ultimately, ALL the finite element model (FEM)-based analyses (FEA) use an abstraction of the "real" geometry in their methods and tools, much like structural simulation and analysis. Early simulation and analyses, usually during the so-called 'feasibility stage', can use very simple cubic geometry with lots of assumptions made based on code or energy standard requirements. Non-FEM methods don't even rely on the model geometry directly and instead use tabulations of element quantities and qualities (e.g., composite 'R-' or 'U-value') for algorithmic operations.

- **Construction and Materiality** are related closely to the previous issues of Geometry Representation and Scope of Modeled Elements, as well as LOX, as to how the geometry and related information (e.g., thermal properties and performance) of construction systems (e.g., walls, flooring, roofs, windows/doors, HVAC, etc.) are created by BIM authoring tools and consumed by simulation and analysis tools.

5.4.4.2 Analytical

Analytical information may be directly related to physical building elements, but also may be distinct abstract information alongside the physical elements and systems and/or logical aggregations which have specific purposes for analysis. For example, in structural analysis, rather than using the *physical* model elements of beams, columns, walls, and slabs, with all their geometric peculiarities and dimensions, these elements are abstracted into simple points (representing joints), axes (3D lines representing vertical or horizontal members), or planes (representing diaphragms such as walls and slabs). These abstractions are the basis for the analytical structural model to which algorithms are then applied. BEM has similar analytical geometric elements, as well as non-geometric information that influences factors of simulation and analysis.

- **Spaces** are the representation of 'rooms' encapsulated by building elements of walls, slabs, ceilings, roofs, and such. While they have no explicit form themselves, in BIM they are usually represented by a cubic volume. Besides the common identification (name, use category, ID numbers, etc.) and physical attributes/properties (length / width / height / volume), other information necessary for simulation and analysis are typically attached/stored with the Space element (e.g., thermal comfort requirements like temp and humidity, illumination levels, human occupancy load, etc.).

- **Space Boundaries** (SBs) are the representation of 'room surfaces', the planes at which the volume of a space is adjacent to walls, ceilings, and floors including planes representing openings and intersections with adjacent walls. These are the abstract analytical geometries most often used by BEM simulation and analysis software to perform calculations.

While relatively simple in concept, SBs can be complex depending on 'levels' of representation[71] and whether 'net', 'gross', or both are needed. And their representation in data schemas like EnergyPlus IDD/IDF, IFC, or gbXML is equally abstract. The detail level and type of SBs needed are dependent on the kind of simulation and analysis, as one specification does not fit all needs. This factor has proved to be most daunting for past IFC-based BIM-BEM data exchange projects, with some of the greatest attention and work on general geometric implementation of the physical elements, yet the least amount of consensus and actual deployment on the analytical surfaces.

- **Zones** are the configuration and identification of areas or aggregation of spaces within a building that have some common physical, thermal, and/or programmatic characteristics, such as an aggregation of exterior rooms along a particular compass direction (N, S, E, W), interior vs. exterior rooms/corridors, or all mechanical service shafts. Such zones may also indicate how Indoor Climate Control systems are then configured to accommodate the varying occupancy comfort needs between thermally distinct areas.
- **Occupancy Types** indicate the kind of activities that the spaces are used for, average or maximum number of occupants (occupancy load), and estimation of the activity (behaviour) and comfort levels required for such use. These are typically dictated by building and/or energy codes/standards per jurisdiction.
- **Psychrometric Properties** are the measured values of the physical and thermodynamic properties of atmospheric air (a gas-vapor mixture) including dry-bulb temperature (DBT), wet-bulb temperature (WBT), dew point temperature, and humidity (specific, absolute, and relative) to name a few. Psychrometric values are typically referenced as performance constraints for Indoor Climate Control systems serving spaces and their occupants.
- **Thermal Bridges** are localized parts of the building construction where heat flow is typically increased over the adjacent surfaces/constructions. A thermal bridge is an undesirable situation, compromising the integrity of an insulating system/strategy which is working to minimize or eliminate unwanted or uncontrolled heat transfer. They can occur as linear (e.g., joints between walls, walls and ceilings, walls and floors, exterior balconies, and walls, etc.) or point (e.g., pipe or wire penetrations through wall/floor/ceiling systems,

[71] See http://www.blis-project.org/IAI-MVD/documents/Space_Boundaries_for_Energy_Analysis_v1.pdf by the US General Services Administration (GSA) Open Geospatial Consortium (OGC) for an in-depth analysis of Space Boundaries for BEM.

HVAC ducting penetrations, structural mounting hardware for appurtenances like balconies or shading devices, etc.) conditions throughout a building.

- **Airtightness** is the ability of a building and its construction systems (e.g., walls, floors, ceilings, windows/doors, etc.) to resist unwanted and uncontrolled airflow (leakages) into (infiltration) or out of (exfiltration) the building envelope. Such leaks typically occur in the same manner and configurations as thermal bridges, as linear or point conditions where the building envelope has been penetrated, allowing air to pass through at varying levels of velocity. Like thermal bridging, airtightness requirements and testing are often integral to building energy performance standards and inspections.

5.5 Energy Standards / Compliance Protocols

Appendix B – Building Energy Efficiency Standards / Protocols provides an extensive list of common building energy performance standards and certification protocols used throughout the world. Any data exchange effort should consider the development of IDMs/MVDs that meet the best common denominators (not the lowest, or only common ones, nor the highest, or most comprehensive, subset) of requirements to meet workflow needs which are based on the varying requirements of these Standards and Protocols. While not every requirement for every standard may be accommodated, it should be easy to recognize where the data exchange may provide enough baseline information in accommodating all of them.

5.6 Software

Currently, there are a significant number of simulation tools that dominate the industry, as shown in **Appendix C – Building Energy Modelling Simulation & Analysis Engines** and noted earlier in section 2.6. Any data exchange effort should consider the development of IDMs/MVDs that meet the ***best common denominators*** (not the lowest, fewest, or only common ones, nor the highest or least common subset) of requirements to meet workflow needs and then examine how different software offerings and methods may be suited to meet those exchanges with reasonable or no further effort. While specific software platforms should NOT dictate the exchange requirements, knowledge of feasibility in used software tools should help inform the type and extent of requirements.

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6 Proposed BIM-to-BEM Project Lifecycle Data Exchanges

6.1 BEM Lifecycle Process Map

Before determining detailed requirements of any single information exchange, it is important to establish a broader, higher-level view of how BEM can be applied to the entire lifecycle of a project. By identifying all the possible data exchanges, or use cases, between BIM and BEM applications and workflows, from early conception through operations, decommissioning, and recommissioning, the community can determine the specific, granular information exchange requirements of each potential BIM-BEM data exchange in a relevant context to all other exchanges. From this larger framework, or roadmap, more detailed use cases, IDMs, and data exchange requirements can be formulated and developed to aid optimal data exchanges at any given point in the project lifecycle.

A complete BEM Lifecycle Process Map is beyond the scope of this report and should be completed in a subsequent project by a larger international group of subject matter experts, within the Building Room, a new Room, or a new Working Group focused on the subject. Such an effort should be part of a review and consensus approval (and/or revisions) of the Proposed BIM-BEM Project Lifecycle Data Exchange Summaries. The content of this report should provide such efforts with a common baseline of information to work from.

An example of a lifecycle process map for BEM can be seen in **Appendix D – Example BIM-BEM Process Map for bSI Design Phase** from Mirbek Bekboliev, PEng., LEED GA, M.Sc. Building Science and Technical Project Manager at buildingSMART Germany. While Mirbek's example is quite detailed and focused only on the design phase, it offers guidance on how to consider the relationship between all the proposed exchanges in a larger, unified lifecycle context. Establishment of a lifecycle 'roadmap' enables consistency and coherency between the subsequent use case specific IDMs.

6.2 Proposed BIM-BEM Data Exchange Summaries

While the previous sections of this report lay the groundwork or baseline for knowledge informing the subsequent bSI Process-based discussions of BIM-BEM data exchanges within the context of BEM workflows over a project lifecycle, the following subsection ***proposes potential data exchanges***, each known as an "**Exchange Model** (**EM**)" in the bSI IDM context, between BIM and BEM stakeholders, tools, and workflows during the lifecycle of a project. Given the desire to consider other datasets and methods of data exchange, the term ***Exchange Model*** **(EM)** is used loosely and should be seen as ***an opportunity of dataset exchange of any or many types***, rather than an exclusive exchange of data in IFC-based, 3D, data-rich, digital model form. These ***proposed*** EMs are an effort to start, and help focus, subsequent conversations and efforts to define the BEM Lifecycle Process Map and appropriate data exchanges from BIM or other sources. They are an initial attempt to find the best common denominator of requirements to fit multiple markets, jurisdictions, tools, methodologies, and project stakeholders. **These proposed EMs are NOT prescriptive**, but general summaries of potential scope and requirements for theoretical opportunities for BIM-to-BEM data exchange. It is expected that after industry review of this report, further commencement of bSI projects to tackle the BEM Lifecycle Process Map and related IDMs and exchanges will better define, through wide review and consensus, the needed exchanges, their scope, and respective requirements. ***Not all proposed EMs are explored, described, or completed to the same level of thoroughness, but will require further input during corresponding more specific IDM developments.***

The following proposed EMs generally summarize the most important aspects of each of the twelve proposed data exchanges. This includes varying degrees of detail and complexities of the factors identified in the previous section **5.3 General Information Requirements**. The following factors are included in each summary:

Project Stage – a generic Project Stage label and a correlating buildingSMART International IDM Stages label have been provided. This enables different markets and jurisdictions to further extrapolate a Project Stage specific to their particular standard practices and requirements;

Exchange Participants – a list of the stakeholders, disciplines and/or roles (see Section 5.2) that are a part of the information exchange, as either the author or receiver of such information;

Description / Purpose of Exchange – A simple plain language description to explain the extents and purpose of the data collection and exchange. This is not a full description of the BIM or BEM processes, but just the data being shared and utilized;

Description / General Information Requirements (GIRs) – A list of required information to serve the Purpose of Exchange;

Description / LOX – a summary of the 'Levels of X', where 'X' is the detail or development of ***geometric and/or data*** requirements;

Description / Special Properties or Attributes – a summary or highlighting of special data points that may be needed to serve the Purpose of Exchange;

Software Functionality – a summary of the data Export and Import requirements for software to successfully complete an exchange as described;

Related Exchange Models – a reference to other EMs described in this document, or possibly other EMs from other IDMs, such as COBie, which may have similar scope and/or GIRs;

Notes – a summary of miscellaneous comments that may help clarify any of the other listed requirements or Purpose of Exchange.

The proposed exchanges attempt to cover a variety of instances where data needs to be exchanged between stakeholders, from the *BIM side* to the *BEM side*, even vice-versa, over a project lifecycle. While they loosely follow a progression from the beginning of a project through construction and occupancy, there is no requirement that they are sequential in use, nor necessary for all to be applied in every project. While they may have related requirements and purposes, it is assumed any one or combination of EMs may be applied to a project as deemed appropriate by overall project execution planning requirements.

The proposed EMs are presented as follows:

EM1 – Energy Performance Requirements & Documentation

EM2 – Spatial Program Requirements

EM3 – Form Feasibility Design & Analysis

EM4 – Initial Architectural Design

EM5 – Initial Engineering Design of Building Services Systems

EM6 – Design Coordination & Feedback

EM7 – Permitting / Regulatory Submission

EM8 – Procurement & Substitutions

EM9 – Requirements for Sensors & Controls

EM10 – Realtime Control, Data Recording & Reporting

EM11 – Comparison of Designed and Actual Performance

EM12 – Documentation of Existing Conditions for Recommissioning

During the development of specific IDMs and data exchange requirements and methods, as suggested by these proposed EMs, the particular aspects listed may evolve but still adhere to a general sensibility of purpose and scope. The following tables summarize the intent, scope, and requirements for each of the proposed EMs. Not all proposed EMs are explored or described to the same level of thoroughness and will require further examination and input during corresponding IDM development. These summaries are providing a basis for further discussion about possible normative processes and sub-processes in BEM throughout a project lifecycle and across an international spectrum, allowing for subject matter experts and end users to determine if the related use cases are relevant and if consensus can be reached on more highly detailed, international standard data exchanges. The EMs are not dictating any particular BIM or BEM workflows, but rather the exchange of data presumed to be necessary for a BIM and/or BEM workflow.

As in the previous example of a Lifecycle Process Map, M. Bekboliev has provided examples of detailed process and sub-process maps for **bSI Design Phase (Appendix D), Preliminary Analyses (Appendix E)**, **Conceptual Analyses (Appendix F)**, and **Detailed Analyses (Appendix G)**. These will offer further guidance to subsequent project to develop IDMs for the various EMs identified in this report.

6.2.1 EM1 – Energy Performance Requirements & Documentation

<table>
<tr><th colspan="2">EM1 – Energy Performance Requirements & Documentation</th></tr>
<tr><td>Project Stage</td><td>Generic: Pre-Design

bSI: 0. Portfolio Requirements</td></tr>
<tr><td>Exchange Participants</td><td>Architect, Owner, BE Consultant</td></tr>
<tr><td>Description</td><td>Purpose of Exchange: Collection of needed data prior to design, to determine constraints and opportunities

General Information Requirements (GIRs):
Site model & plans w/ geolocation data
Climate data, typically EPW format
Energy performance standard
Energy costs (actual & projected)
Building codes
Planning & zoning codes/requirements
Economic incentives from Energy Suppliers / local regulators
LOX: Low to moderate geometric site detail, moderate to high level of information for GIRs listed above

Special properties or attributes: N/A</td></tr>
<tr><td>Software Functionality</td><td>Export: N/A

Import: EPW climate data; Site models via IFC, CityGML, GML/KML, or SHP files. DWG, though proprietary, is also a common format for graphical site data.

Multiple file formats may require translation/transformation by intermediary products or processes to be used in BIM-BEM tools.</td></tr>
<tr><td>Related EMs</td><td>EM2, EM3</td></tr>
<tr><td>Notes</td><td>Some tools used at this, and subsequent stages, may be able to automatically collect the General Information Requirements internally, based on geolocation data.</td></tr>
</table>

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6.2.2 EM2 – Spatial Program Requirements

EM2 – Spatial Program Requirements	
Project Stage	Generic: Pre-Design (Schematic Design) bSI: 0. Portfolio Requirements, 1. Conception of Need
Exchange Participants	Architect, Building Services Engineer, Owner
Description	**Purpose of Exchange:** Collection of detailed functional requirements of areas/rooms/spaces, determining minimum building size/scale, as well as aggregated performance requirements **General Information Requirements:** • Room/Space functional descriptions • Room/Space sizes (area, volume) • Psychrometric (human comfort) baselines for occupant comfort including lighting levels, temperature, humidity, air quality, etc. • Building and Occupancy code requirements in determining occupant load and distribution (e.g., occupancy schedules, lighting levels, plug load density, infiltration/ventilation rates, etc.) **LOX:** • Low geometric detail of building spatial elements which may initially be 2D plan-only or simple 3D cubic forms representing general space requirements • Building model consists of aggregation of spatial volumes within a simple envelope, or implied envelope through aggregated massing form **Special properties or attributes:** N/A
Software Functionality	**Export:** BIM authoring tool for functional/spatial programming – IFC export of space objects **Import:** BEM tool for massing model simulation & analysis
Related EMs	EM1, EM3

EM2 – Spatial Program Requirements	
Notes	A variety of applications can be applied to Spatial / Functional Programming, including primary BIM-authoring or purpose-built tools. The intent is to have an independent 'spatial model' which describes the form of the building based on the spatial displacement of functional requirements instead of a form defined by constructed forms, materials, and systems.

6.2.3 EM3 – Form Feasibility Design & Analysis

<table>
<tr><th colspan="2">EM3 – Form Feasibility Design & Analysis</th></tr>
<tr><td>Project Stage</td><td>Generic: Pre-Design (Schematic Design)

bSI: 2. Outline Feasibility / 3. Substantive Feasibility</td></tr>
<tr><td>Exchange Participants</td><td>Architect, Building Services Engineer, BE Consultant, Owner</td></tr>
<tr><td>Description</td><td>Purpose of Exchange: Early studies of overall building form (aka ‘Massing Model’), site location, surrounding physical context, and orientation strategies to determine economic and performance feasibility of project.

General Information Requirements (GIRs):
‘Massing Model’ - Gross Building Area(s) & Volume(s)
Site model w/geolocation data
See GIRs in EM1 for performance, code, and climate data
LOX:
Low to moderate geometric site detail, including relevant surrounding natural and built context, and with proper geolocation and orientation;
Low building/massing model 3D geometric detail, including potential building stories (single space/zone per story or spaces per aggregated functional requirement), possible fenestration location, configuration, and general extents, indication of shading structures/devices;
Window-Wall ratio for calculation of internal heat gains/loss
Generalized analytical attributes, usually ‘rule of thumb’ generalizations for estimating possible, or baseline, building thermal performance, and energy requirements.
Special properties or attributes: N/A</td></tr>
<tr><td>Software</td><td>Export: BIM-authoring tool for massing model studies - IFC</td></tr>
</table>

EM3 – Form Feasibility Design & Analysis	
Functionality	export of building and/or site model with correct orientation and geolocation **Import:** BEM tool for massing model simulation & analysis (e.g., microclimate analyses, solar paths, direct solar gains and shading, environmental airflows, etc.) - IFC Import, import of EPW data, import or input of GIRs collected in EM1
Related EMs	EM1, EM2
Notes	1. Some BIM and BEM tools used at this, and subsequent stages, may be able to automatically collect the General Information Requirements internally, based on geolocation data. 2. BIM tool may or may not input non-geometric data (performance, cost, code, and climate) and pass along to BEM tool 3. Some BIM authoring tools may allow for this stage of BEM simulation and analysis to be done internally, but it should be possible to export model data to a separate BEM application for independent simulation and verification of results. 4. May also be a reiterative process, with multiple versions, before settling on a design strategy that meets all performance, functionality, and investment criteria

6.2.4 EM4 – Initial Architectural Design

EM4 – Initial Architectural Design	
Project Stage	Generic: Design (Initial Design Development) bSI: 4. Outline Conceptual Design
Exchange Participants	Architect, Building Services Engineers, BE Consultant *Landscape Architect and Civil Engineer (optional)*
Description	**Purpose of Exchange:** Establishing architectural baseline for all other disciplines to commence baseline design and systems layouts. The second opportunity to measure potential project performance against baseline requirements. **General Information Requirements (GIRs):** • Generic depiction of construction systems (e.g., exterior walls, interior walls, floor/ceiling/roof, fenestration locations and extents • Space or Room objects depicting 3D extents of inhabitable spaces with required occupancy and psychrometric (human comfort) values for occupant comfort including lighting levels, temperature, humidity, air quality, etc. • Exterior design elements that may affect building performance (e.g., shading devices, PV locations) • Adjacent context elements which may affect performance (e.g., adjacent buildings, roads, trees, bodies of water and other extensive physical geography) **LOX:** • Moderate architectural/building element detail – approximate component/system thicknesses, but not detailed component assemblies. Aggregate thermal values and texture/colour depiction of exterior claddings have higher priority; • Moderate fenestration element/system detail – generic indication of unitized glazing system types and extents. Performance values and depiction of

EM4 – Initial Architectural Design	
	adjacent shading devices have higher priority • Low to moderate adjacent context elements. Accurate size/extents of elements that may affect shading and air flow have priority over material and formal detail **Special properties or attributes:** N/A
Software Functionality	**Export:** BIM-authoring tool for architectural design – IFC 'reference' export **Import:** BIM-authoring tool for Structural and Building Services *(landscape and civil – optional)* design – IFC 'reference' import of architectural model BIM viewer for quality assurance / quality checking, validating model has met standard and user-defined exchange requirements – IFC 'reference' import of architectural model. Ability to highlight and report errors. Use of standard 'rulesets' based on MVD and added user requirements BEM tool for validating concept – IFC import of architectural model, or a specific subset (e.g., spatial model with Space Boundaries, materials/system performance attributes, and psychrometric values)
Related EMs	EM1, EM2, EM5
Notes	1. BIM authoring tool should have ability to capture and assign relevant data (performance, cost, classification) to geometry and pass along to BEM and other analysis tools 2. Some BIM authoring tools may allow for this stage of BEM simulation and analysis to be done internally, but it should be possible to export model data to a separate BEM application for independent simulation and verification of results. 3. May also be a reiterative process, with multiple versions, before settling on a design strategy that meets all performance, functionality, and investment criteria

6.2.5 EM5 – Initial Engineering Design of Building Services Systems

<table>
<tr><th colspan="2">EM5 – Initial Engineering Design of Building Services Systems</th></tr>
<tr><td>Project Stage</td><td>Generic: Design (Initial Design Development)

bSI: 4. Outline Conceptual Design</td></tr>
<tr><td>Exchange Participants</td><td>Architect, Engineer, BE Consultant, Owner</td></tr>
<tr><td>Description</td><td>Purpose of Exchange: Establishing initial building services system design and layout baselines based on initial architectural design. The second opportunity to measure potential project performance against baseline requirements.

General Information Requirements (GIRs):
Generic depiction of building services systems (e.g., HVAC, Plumbing, Lighting, Power, Communications, etc.).
Generic sizing and location of utility services (e.g., power, water, sewer) including any on-site power generation systems and strategies (e.g., fuel cell, PV, wind, etc.)
Space or Room objects depicting 3D extents of inhabitable spaces with required occupancy and psychrometric (human comfort) values for occupant comfort including lighting levels, temperature, humidity, air quality, etc.
Energy pricing
LOX:
Includes ‘single-line’ or axis delineation of piping and ducting, as well as schematics of central HVAC, power, and comm systems. Initial power and thermal load values.
Generic artificial and daylighting schemas
Special properties or attributes: N/A</td></tr>
<tr><td>Software Functionality</td><td>Export: BIM-authoring tool for building systems design – IFC ‘reference’ export</td></tr>
</table>

EM5 – Initial Engineering Design of Building Services Systems	
	Import: BIM-authoring tool for architectural design – IFC ‘reference’ import of building services model(s) BIM viewer for quality assurance / quality checking, validating model has met standard and user-defined exchange requirements – IFC ‘reference’ import of building services model(s). Ability to highlight and report errors. Use of standard ‘rulesets’ based on MVD and added user requirements BEM tool for validating concept – IFC import of building services model(s) with architectural model from EM4
Related EMs	EM1, EM2, EM4
Notes	1. BIM authoring tool should have ability to capture and assign relevant data (performance, cost, classification) to geometry and pass along to BEM and other analysis tools 2. Some BIM authoring tools may allow for this stage of BEM simulation and analysis to be done internally, but it should be possible to export model data to a separate BEM application for independent simulation and verification of results. 3. May also be a reiterative process, with multiple versions, before settling on a design strategy that meets all performance, functionality, and investment criteria 4. Benchmarking requirements can also be included in terms of energy, environmental and economic performance, using key metrics per building type such as the intensity of energy use (EUI) and the energy cost index (ICE), which express the use and cost of energy of the building according to its size, respectively.

6.2.6 EM6 – Design Coordination & Feedback

EM6 – Design Coordination & Feedback	
Project Stage	Generic: Design bSI: 6. Coordinated Design & Procurement
Exchange Participants	Architect, Engineer, BE Consultant, General Contractor, Product Manufacturer / Supplier, Owner
Description	**Purpose of Exchange:** Reiterative process of exchanging domain/discipline models between project design team members to coordinate the geometric and performative aspects of the overall formal design and systems to a high level of detail for costing, procurement, and construction purposes. **General Information Requirements:** • Specific depiction of construction systems (e.g., exterior walls, interior walls, floor/ceiling/roof, fenestration locations and extents • Space or Room objects depicting 3D extents of inhabitable spaces with required occupancy and psychrometric (human comfort) values for occupant comfort including lighting levels, temperature, humidity, air quality, etc. • Exterior design elements that may affect building performance (e.g., shading devices, PV locations) • Site model and adjacent context elements which may affect performance (e.g., adjacent buildings, roads, trees, bodies of water and other extensive physical geography) • Specific depiction of building services systems (e.g., HVAC, Plumbing, Lighting, Power, Communications, etc.). • Specific sizing and location of utility services (e.g., power, water, sewer) including any on-site power generation systems and strategies (e.g., fuel cell, PV, wind, etc.)

EM6 – Design Coordination & Feedback	
	LOX: • High architectural/building element detail – exact component/system thicknesses and detailed component assemblies. High fenestration element/system detail – exact indication of unitized glazing system types and extents. Thermal values and material depiction of each component; • Low to moderate site and adjacent context elements. Accurate size/extents of elements that may affect shading and air flow have priority over material and formal detail • Specific geometric delineation (cross section sizes, lengths, fitting locations) of piping, ducting, and conduits, as well as mechanical, power, and comm equipment. Specific power, performance, and thermal load values. • Specific artificial and daylighting schemas **Special properties or attributes:** N/A
Software Functionality	**Export:** BIM-authoring tool for architectural and building systems design – IFC 'reference' export **Import:** BIM-authoring tool for architectural and building systems design – IFC 'reference' import all models BIM viewer for quality assurance / quality checking, validating model has met standard and user-defined exchange requirements – IFC 'reference' import of all model(s). Ability to highlight and report errors. Use of standard 'rulesets' based on MVD and added user requirements BEM tool for validating concept – IFC import of all model(s)
Related EMs	EM4, EM5
Notes	1. BIM authoring tool should have ability to capture and assign relevant data (performance, cost, classification) to geometry and pass along to BEM and other analysis

EM6 – Design Coordination & Feedback	
	tools 2. Some BIM authoring tools may allow for this stage of BEM simulation and analysis to be done internally, but it should be possible to export model data to a separate BEM application for independent simulation and verification of results. 3. May also be a reiterative process, with multiple versions, before settling on a design strategy that meets all performance, functionality, and investment criteria

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6.2.7 EM7 – Permitting / Regulatory Submission

EM7 – Permitting / Regulatory Submission	
Project Stage	Generic: Construction bSI: 6. Coordinated Design and Procurement
Exchange Participants	Architect, Engineer, BE Consultant, General Contractor
Description	**Purpose of Exchange:** Aggregation of 'final' design version of all domain models for review by building permitting authorities. It may be used for automated code checking and for regulatory approval based on building energy performance. **General Information Requirements:** Same as EM6: **LOX:** Same as EM6: **Special properties or attributes:** N/A Graphical and non-graphical indications of designed conditions meeting regulatory requirements (e.g., occupancy, exiting, thermal performance values, solar paths and shadow casting diagrams, false-colour renderings of solar gain/loss, etc.). Varies by jurisdiction and BEM compliance protocols.
Software Functionality	**Export:** BIM-authoring tool for architectural and building systems design – IFC 'reference' export **Import:** BIM viewer for quality assurance / quality checking, validating model has met standard and user-defined exchange requirements – IFC 'reference' import of all model(s). Ability to highlight and report errors. Use of standard 'rulesets' based on MVD and added user requirements BIM tool for validating design submission to meet building code requirements BEM tool for validating design submission to meet compliance protocol requirements (e.g., LEED, MINERGIE, BREEAM, etc,)

EM7 – Permitting / Regulatory Submission	
Related EMs	EM6
Notes	While the tools for automated building code analysis will probably differ from the BEM validation tools, both should be able to operate on the same overall extent of model content.

6.2.8 EM8 – Procurement & Substitutions

<table>
<tr><th colspan="2">EM8 – Procurement & Substitutions</th></tr>
<tr><td>Project Stage</td><td>Generic: Pre-Construction (Procurement)

bSI: 6. Coordinated Design & Procurement, 07. Production Information</td></tr>
<tr><td>Exchange Participants</td><td>Architect, Engineer, BE Consultant, GC, Product Manufacturer / Supplier, Commissioning Agent, Owner</td></tr>
<tr><td>Description</td><td>Purpose of Exchange: During the process of procuring specified materials, elements, and systems the domain model(s) or aggregated model is updated to reflect information on specific products selected and purchased for installation/fabrication.

General Information Requirements:
Same as EM7, but adding:
Indications of revisions to design elements during the procurement process.
Collection and reporting of procured and installed building element and product specifications
LOX:

Same as EM7, but adding:
Detailed building element and product specifications, especially those that directly affect operational and thermal performance
Special properties or attributes: N/A</td></tr>
<tr><td>Software Functionality</td><td>Export: BIM-authoring tool for architectural and building systems design – IFC ‘reference’ export

Import: BIM viewer for quality assurance / quality checking, validating model has met standard and user-defined exchange requirements – IFC ‘reference’ import of all model(s). Ability to highlight and report errors. Use of standard ‘rulesets’ based on MVD and added user requirements

BEM tool for validating revised data to meet compliance protocol requirements (e.g., LEED, MINERGIE, BREEAM, etc,) and measure against previous BEM simulation and</td></tr>
</table>

EM8 – Procurement & Substitutions	
	analysis
Related EMs	EM6, EM7, EM9, EM10 COBie
Notes	The detailed reporting of values of specific elements and products is used to update the relevant model elements to validate performance against baseline established in EM6 and/or EM7.

745 ### 6.2.9 EM9 – Requirements for Sensors & Controls

EM9 – Requirements for Sensors & Controls	
Project Stage	Generic: Pre-Construction (Procurement) bSI: 6. Coordinated Design & Procurement, 07. Production Information
Exchange Participants	Engineer, BE Consultant, GC, Product Manufacturer / Supplier, Commissioning Agent
Description	**Purpose of Exchange:** Collection of power and communication requirements for sensors and controls of HVAC, lighting, and any other automated systems which have an influence on thermal performance and occupant comfort **General Information Requirements:** • System and Device identification • IoT Data Protocols • IoT Network Protocols • IoT Security Protocols/Requirements/Standards (e.g., NIST 800 Series https://www.nist.gov/itl/publications-0/nist-special-publication-800-series-general-information) **LOX:** • May be equal to EM7 with additional GIRs **Special properties or attributes:** N/A
Software Functionality	**Export:** … **Import:** …
Related EMs	EM6, EM7, EM8 COBie
Notes	1. Consider information from field level (e.g., device specification, geolocation), control level (e.g.,, logical connection, schedules, setpoints) and supervisory level (e.g.,, alarms, events, historical data access). 2. This EM may also consider the different Building

EM9 – Requirements for Sensors & Controls	
	Automation System (BAS) communication protocols, data representations and interfaces (in terms of requirements and software functionalities)

6.2.10 EM10 – Realtime Control, Data Recording & Reporting

<table>
<tr><th colspan="2">EM10 – Realtime Control, Data Recording & Reporting</th></tr>
<tr><td>Project Stage</td><td>Generic: Operations & Maintenance

bSI: 9. Operations & Maintenance</td></tr>
<tr><td>Exchange Participants</td><td>Engineer, BE Consultant, Product Manufacturer / Supplier, Commissioning Agent</td></tr>
<tr><td>Description</td><td>Purpose of Exchange: Collection of data transmitted by sensors and controls, such as log files, for historical and analytical reporting.

General Information Requirements:
Manufacturer and performance information of the installed devices including the unique ID along with the spatial location
Readings from installed devices (Status, Measurable Quantities Accumulation, etc.)
System connection and communication between the devices
Integration and/or capture and reporting of the live data obtained from sensors
LOX: N/A

Special properties or attributes: N/A</td></tr>
<tr><td>Software Functionality</td><td>Export: …

Import: …</td></tr>
<tr><td>Related EMs</td><td>EM9</td></tr>
<tr><td>Notes</td><td>IoT security protocols and Requirements (e.g., NIST 800)
A Monitoring Plan may be part of the EM requirements indicating intent of the monitoring system design and comparing to the actual installed conditions and system operating and reporting results.</td></tr>
</table>

EM10 – Realtime Control, Data Recording & Reporting	
	3. May consider static and dynamic database management systems to store and retrieve the data collected by the sensors and controllers.

6.2.11 EM11 – Comparison of Designed and Actual Performance

EM11 – Comparison of Designed and Actual Performance	
Project Stage	Generic: Operations & Maintenance, Recommissioning / Decommissioning bSI: 9. Operations & Maintenance, 10. Disposal
Exchange Participants	Architect, Engineer, BE Consultant, Commissioning Agent, Owner
Description	**Purpose of Exchange:** Collection of model and data from EM7, EM8, EM9, and EM10 to be used for comparison between design and historical performance of project (e.g., post-occupancy evaluation). **General Information Requirements:** • All model data from EM7, submitted for permitting as representation of final design • All 'as-built' data from EM8 and EM9 as representation of final installed conditions turned over to owner • All historical data from EM10 as representation of actual performance **LOX:** Geometric and information detail may increase as the complexity of the design and analysis tasks also increases in subsequent EMs. The BEM expert will need to determine which previous design and analysis models will be applicable in the comparison of the building's performance **Special properties or attributes:** N/A
Software Functionality	**Export:** … **Import:** …
Related EMs	EM7, EM8, EM9, EM10 COBie
Notes	N/A

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6.2.12 EM12 – Documentation of Existing Conditions for Recommissioning

EM12 – Documentation of Existing Conditions for Recommissioning	
Project Stage	Generic: Pre-Design, Recommissioning / Decommissioning bSI: 9. Operations & Maintenance, 10. Disposal
Exchange Participants	Architect, Engineer, BE Consultant, Owner
Description	**Purpose of Exchange:** Collection of geometry and data from existing conditions in making informed decisions related to energy performance in a project recommissioning (also known as retrofit or refurbishment). **General Information Requirements:** • Climate data • Energy costs • Adjacent context elements which may affect performance (e.g., adjacent buildings, other extensive physical geography) • Spaces and Thermal Zones • Occupancy • Last 3-5 years bills related to energy consumption • Exterior envelope and thermal characteristics of opaque and transparent assemblies • Presence and analysis of thermal bridges • Restoration works done during the lifetime of the building • Structural characteristics of foundations, walls, slabs, etc. • Unoccupied spaces such as attics, cellars, etc. • Existing Building Services systems (aka MEP – Mechanical-Electrical-Plumbing) • Renewable energy systems • Vertical transport systems (lifts, escalator, etc.)

EM12 – Documentation of Existing Conditions for Recommissioning	
	• Artificial lighting and daylighting systems • Mandatory building codes and standards • Mandatory energy efficiency standards and/or performance improvement incentives • Former certifications such as: • Building permit authorization / occupancy permit • Historical preservation / protection • Energy / sustainability performance certificate (e.g., LEED, BREAM, etc.) • Structural suitability • … **LOX:** The level of information of an existing building could be very accurate via LIDAR survey, but during a preliminary energy analysis it is useless to have such a detailed geometric model as it considers only the volumes enclosed by walls, ceiling, windows, etc. Most BIM and BEM applications require the translation to rationalized 3D models with regularized surfaces and semantic definitions. **Special properties or attributes:** N/A
Software Functionality	**Export:** Point cloud data from LIDAR scanning (point cloud) of existing conditions **Import:** Point clouds
Related EMs	EM1, EM2, EM3 COBie
Notes	1. Historical buildings are usually very different from each other as much as modern structures. Typical software parametric features are not usable for modelling and energy analysis, as the physical and thermal characteristics are very different from modern structures. For this reason, a new database for the definition of these characteristic is recommended. The structure of

EM12 – Documentation of Existing Conditions for Recommissioning	
	this data base should be based on the same standards used for bSDD. 2. Some ESCos may require, during the preliminary analysis, interviews with occupants for the correct sizing of HVAC to meet the needs of the occupants. 3. When dealing with an existing building, especially if the building is historical, the drawings deposited in the different authorization offices seldom coincide with the existing conditions. When the documentation is insufficient or not reliable, it is necessary a survey with the use of laser scanning (LIDAR) and/or photogrammetry to acquire reliable geometric data. This can then be integrated with any energy performance parameters necessary for energy simulation. 4. Existing building services systems may need to be identified by manual survey and entered into a BIM system to find any possible improvement and/or constraints to use more efficient technologies. 5. Any normative and cultural protection constraints must be documented to avoid disallowed interventions

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7 Recommendations

As introduced, the purpose of this report is to provide a high-level overview of the challenges of BIM-BEM workflows and needed data exchanges in the context of buildingSMART openBIM principles and the desire to utilize the IFC schema, as well as any other valid open standard methods. This first step can be seen as a roadmap to help set the stage for more detailed development of IDMs and resulting technical specifications for the proposed BIM-BEM Lifecycle Data Exchanges / Exchange Models identified in Chapter 6.

7.1 Considerations for Further IDM / Data Exchange Development

In pursuit of the further development of detailed IDMs and technical data exchange specifications based on the identified Exchange Models, this report has documented significant factors for consideration. Recognizing the importance and impact all these factors have on making decisions to create international standard exchanges should help in reaching an international consensus. But there are further, if indirect, factors to consider in the process to create BIM-BEM data exchange standards within the bSI community.

7.1.1 Data Schema(s)

If subsequent IDM developments for specific exchanges determine an IFC schema is to be used, a decision needs to be made early regarding the version. While many building domain software vendors have been engaged in IFC2x3 and IFC4.0 development, implementation and certification, a transition to supporting BIM-BEM data exchanges using IFC4.3/IFC4.x may be deemed necessary. It is possible to further detail and formulate requirements for all the proposed EMs to include support for IFC2x3, IFC4, IFC4.3, IFC4.x, and even the future with recommendations for the next generation/version of IFC (aka “IFC5”). There is still extensive use and support for IFC2x3 and the same may be found in the future for IFC4 and IFC4.x. For best results, subsequent projects may determine it is necessary to further revise, extend, or enhance any IFC schema, or provide standard guidelines and documentation for modeling and usage, to better capture required geometry and related information (e.g., Space Boundary geometry and its relation to bound Spaces and adjacent constructions like walls, floors, ceilings, openings, etc.). As soon as possible, there should also be agreements to make schema recommendations to the Technical Director and the IFC5 Task Force in improving data capture and exchange for BIM-BEM workflows.

However, it may be that the BIM and BEM stakeholders also determine that IFC-based workflows are not ideal for ALL data exchanges and BEM processes. Instead, the bSI community may consider integrating gbXML, CityGML ADEs, and/or other methods to cover the requirements of identified use cases in the most appropriate manner. As long as the formats and/or methods meet the core principles of bSI – open, non-proprietary, international, and consensus-driven – then these alternatives might prove valuable options to supplement IFC-based workflows, data sets, and exchanges. Similar to the potential for recommending additions/changes to the IFC schema, if used, subsequent data exchange projects should be able to make recommendations to improve another schema/method for optimal usage.

7.1.2 Standardized Data Exchanges vs. Standard Guidelines/Frameworks

The process of reviewing and comparing the BIM-BEM processes, requirements, and software across multiple markets/jurisdictions may present that there cannot be a consensus on creating specific international standard (e.g., bSI, CEN, or ISO) data exchanges, whether through a Model View Definition (MVD), Information Delivery Specification (IDS) or other method. In this case, the bSI community should consider developing rational, global ***frameworks***, or ***guidelines***, for BIM-BEM workflows that can still guide the development of specific data exchanges for single or multiple jurisdictions but remain true to consensus principles and consensus-based strategies, as well as bSI foundational standard (e.g., IFC, BCF, the bSDD) and other open standard technologies and methods. The focus of such frameworks/guidelines would be on the creation and inclusion of necessary data, as well as geometry, for a specified model-based workflow between BIM and BEM tools. Such frameworks/guidelines should be careful to consider practical balancing of the responsibility for information between the various disciplines and tools so as not to unduly burden one or another. Such burden may not lead to the desired overall data exchange because the tools are simply unable to meet the requirements in as much the users of those tools.

7.1.3 BIM-BEM within Larger Context(s)

Another consideration is the relationship of BIM-BEM to Lifecycle Cost Analysis (LCA or LCCA) and the broader vision of Sustainable Design including environmental impact with such factors as embodied carbon of materials and products; fuel sources and energy pricing; replacement costs and availability of long-term supply-chain for replacement materials and products; and water use and dependence, to name a few. M. Bekboliev has emphasized that the recognition of global climate change pressures must have a fundamental impact in the way buildings and infrastructure are initially considered, designed, and operated, with more emphasis on having less harmful impact on the global environment in the long term.

There are also the larger physical contexts beyond a single building or built asset project, such as an educational, institutional, or corporate campus, an urban neighborhood, or entire metropolitan region. Contextual modeling at these larger scales may account for the impact of surrounding buildings and built environment upon a building as well as the inverse.

The concept of Digital Twins is now front of mind for everyone in the built asset industry. While some of the proposed EMs address such potential Digital Twin use cases, such as IoT-based sensors and controls, as well as predictive simulation and analysis, the full scope of the Digital Twin concept should also be considered during the further development of EMs and their associated use cases, intent, and requirements.

7.2 Commencing bSI Process

Moving forward, the following recommendations should be considered in that continuing process:

1. Review, Revision, and Approval of Report
2. Consensus Agreement on BIM-BEM Roadmap
3. Establish a BEM Working Group
4. Prioritize IDM / Data Exchange Development
5. Identification of Project Resources
6. Launch BIM-BEM IDM / Data Exchange Development Projects

7.2.1 Review and Approval of Report

An Expert Panel has reviewed the 1.0 version of this report, providing feedback in the form of comments and questions in the formal Comment Log. Applicable responses to such feedback and subsequent revisions by the authors have been included in the 1.1 version of the report. This revised version of the report was created for submission of final approval and recommendation to the Building Room Steering Committee (BRSC), the Standards Committee Executive (SCE), as well as the Standards Committee Technical Executive (SCTE) when necessary, and finally the Standards Committee (SC) for voting. Feedback and comments from these reviewers shall be collected and discussed, as well as any further questions for the report and answers from the authors recorded. The approved final version shall be published in the bSI Standards Library and made publicly available. Any additional public commentary and feedback should be collected via the bSI Forums at https://forums.buildingsmart.org/.

If possible, publicly available reference material in this project's 'Precedent' folder should also be available to all bSI reviewing and governing bodies, as well as the general bSI community and industry at-large. While not exhaustive, the precedent material provides more context to the report and subsequent work to develop IDMs and detailed exchanges.

The Comment Logs from the Expert Panel reviewers shall be available to the bSI governing committees and participating Panelists, but not the general public. Some items from the Comment Logs may be published as a *Commentary* appendix or addendum to the report, highlighting comments from the Expert Panel which didn't directly affect revision of the Report, but were important context to the reading of it and subsequent actions.

7.2.2 Establish a Topical Working Group

Since the scope of the work beyond this report is quite vast, it is important to establish a BIM-BEM Working Group (WG) within an existing or new Room in the Solutions and Standards Program to coordinate further activities in the development of specific IDMs / Data Exchanges as identified. The working group may include Expert Panel members, but should also include a variety of Software Vendor, bSI Chapter, existing Room, and partner organization representatives. This body will also need access to all reference material located in this project's folder.

7.2.3 Consensus Agreement on BEM Roadmap

As a first order of business, it is recommended that the working group create a bSI community ***Consensus Agreement*** validating the report and roadmap for further IDM / Data Exchange development. The document may be a further addendum and/or appendix to the published version of this report.

7.2.4 Prioritize IDM / Data Exchange Development

As a second order of business for the BIM-BEM Working Group, prioritization of development of specific IDMs / Data Exchanges to meet the roadmap and proposed Exchange Models should be defined and formalized. This will aid the community in tackling the scope of the overall project by identifying the BIM-BEM exchanges that may be the most beneficial to implement as soon as possible, or enable multiple projects to commence simultaneously, with tight coordination between the different developments.

7.2.5 Identification of Project Resources

To ensure successful execution of projects developing the identified IDMs / data exchanges, the BIM-BEM Working Group should work to identify the necessary resources necessary prior to launching these efforts. Such initial work would help Project Initiators with formulating Project Execution and give confidence to the reviewing committees that the efforts have momentum to proceed and succeed. This includes:

- **Project management** – This includes Proposal Initiators / Authors for Activity Proposals and Detailed Project Plans (APs and DPPs), as well as Project and possible Task Force/Working Group leaders;
- **Project participants** – Care should be taken to develop as broad a scope as possible to establish a credible consensus across markets and stakeholders;
- **Sponsors and Funding** – This includes securing enough in-kind and cash donations to ensure fair value compensation and accounting for all efforts. Some projects may require more than others, but ample opportunities should be afforded many different levels of needed expertise contribution;

7.2.6 Launch BEM IDM / Data Exchange Development Projects

Finally, but not the least significant, Activity Proposals and Detailed Project Plans should be created for each of the activities/projects and reviewed by the various bSI governing committees as prescribed in the bSI Process documentation[72]. The required documentation for any and all APs and DPPs should leverage and directly reference the contents of this report to maintain continuity and consistency in background information, intent, market/domain opportunities and more.

It is highly recommended that the new Use Case Management Service (UCMS) https://ucm.buildingsmart.org/ by buildingSMART International be used by all subsequent BIM-BEM data exchange activities as a means to consistently document each IDM and data exchange requirements, enabling such features as sharing and reusing ERs across multiple, related IDMs. All such BIM-BEM use cases should be managed by the working group, a designated Room and/or representative.

End of Report

[72] See https://www.buildingsmart.org/about/bsi-process/

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8 Appendices

The following appendices include tables of additional information referenced by the report. While extensive, they are not exhaustive and are open to further input to cover the surveys of information they address more adequately.

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Appendix A – Academic and Industry Research References

Paper Name	Source / Publication	Authors	URL	File name (if available)
A comparative study of the IFC and gbXML informational infrastructures for data exchange in computational design support environments	Paper presented at Building Simulation 2007, BS 2007, Beijing, China.8 p.	Dong, B. ; Lam, K. P. ; Huang, Y. C. ; Dobbs, G. M.	https://experts.syr.edu/en/publications/a-comparative-study-of-the-ifc-and-gbxml-informational-infrastruc	p363_final.pdf
A Tool for IFC Building Energy Performance Simulation Suitability Checking	eWork and eBusiness in Architecture, Engineering and Construction, Proceedings of the 12th European Conference on Product and Process Modelling (ECPPM 2018), September 12-14, 2018, Copenhagen, Denmark	Lilis, G.N., G. Giannakis, K. Katsigarakis, e D.V. Rovas	https://doi.org/10.1201/9780429506215-8	
An automated IFC-based workflow for building energy performance simulation with Modelica	Automation in Construction, Volume 91, 2018, Pages 166-181, ISSN 0926-5805	Ando Andriamamonjy, Dirk Saelens, Ralf Klein	https://doi.org/10.1016/j.autcon.2018.03.019	
An IFC Data Preparation Workflow for Building Energy Performance Simulation	Proceedings of the 2019 European Conference on Computing in Construction, 2019, pp. 164-171, University College Dublin, 9781910963371	Katsigarakis, Kyriakos I, Georgios I Giannakis, Georgios Nektarios Lilis, e Dimitrios V Rovas	https://doi.org/10.35490/EC3.2019.188	Contribution_188_final.pdf
An interoperability workbench for design analysis integration	Energy and Buildings, Volume 36, Issue 8, 2004, Pages 737-748, ISSN 0378-7788	Godfried Augenbroe, Pieter de Wilde, Hyeun Jun Moon, Ali Malkawi	https://doi.org/10.1016/j.enbuild.2004.01.049	
An open framework for integrated BIM-based building performance simulation using Modelica	Proceedings of BS2015: 14th Conference of International Building Performance Simulation Association, Hyderabad, India, Dec. 7-9, 2015.	P. Remmen, J. Cao, S. Ebertshäuser, J. Frisch, M. Lauster, T. Maile, J. O'Donnell, S. Pinheiro, J. Rädler, R. Streblow, M. Thorade, R. Wimmer, D. Müller, C. Nytsch-Geusen, C. van Treeck	http://www.iea-annex60.org/downloads/p2384.pdf	p2384.pdf
BIM - Geometry modelling guidelines for building energy performance simulation	Proceedings of BS 2013: 13th Conference of the International Building Performance Simulation Association	Maile, Tobias; O'Donnell, James; Bazjanac, Vladimir; Rose, Cody	http://hdl.handle.net/10197/11016	2013_Maile_2013_IBPSA.pdf
BIM as multiscale facilitator for built environment analysis : master thesis	University of Ljubljani, Faculty of Civil and Geodetic Engineering, 2020	MANDRILE, Matteo	https://repozitorij.uni-lj.si/IzpisGradiva.php?lang=slv&id=121115	4039.pdf
BIM IFC information mapping to building energy analysis (BEA) model with manually extended material information	Automation in Construction, Volume 68, 2016, Pages 183-193, ISSN 0926-5805	Hyunjoo Kim, Zhenhua Shen, Inhan Kim, Karam Kim, Annette Stumpf, Jungho Yu	https://doi.org/10.1016/j.autcon.2016.04.002	
BIM to Building Energy Performance Simulation: An Evaluation of Current Transfer Processes	IBPSA 2019, Corrado, V., Fabrizio, E., Gasparella, A. and Patuzzi, F. Building Simulation 2019, ISSN 2522-2708	van Dessel, Megan; Maile, Tobias; O'Donnell, James	http://hdl.handle.net/10197/12264	Megan_BS2019_210241.pdf
BIM2SIM: Model-based Building Performance Simulation	buildingSMART Virtual Summit Fall 2020, 03 November 2020	Manual Frey		201103_bSI_BR_BIM2SIM.pdf
Building Energy Modeling for Owners and Managers: A Guide to Specifying and Securing Services	Rocky Mountain Institute, Rocky Mountain Institute (2013): 30.	Franconi, E., Tupper, K., Herrschaft, B., Schiller, C. and Hutchinson, R.	https://rmi.org/insight/building-energy-modeling-for-owners-and-managers-a-guide-to-specifying-and-securing-services/	Building-Energy-Modeling-for-Owners-and-Managers-2013.pdf
Building information modeling for energy retrofitting – A review	Renewable and Sustainable Energy Reviews, Volume 89, 2018, Pages 249-260, ISSN 1364-0321	Luís Sanhudo, Nuno M.M. Ramos, João Poças Martins, Ricardo M.S.F. Almeida, Eva Barreira, M. Lurdes Simões, Vítor Cardoso	https://doi.org/10.1016/j.rser.2018.03.064	Building_information_modeling_for_energy_retrofitting-2018_06.pdf
Building information modelling based building energy modelling: A review	Applied Energy, Volume 238, 2019, Pages 320-343, ISSN 0306-2619	Hao Gao, Christian Koch, Yupeng Wu	https://doi.org/10.1016/j.apenergy.2019.01.032	
CityGML Import and Export for Dynamic Building Performance Simulation in Modelica	Building Simulation and Optimization 2016 : Third IBSPA - England Conference, BSO2016, 2016-09-12 - 2016-09-14, Newcastle upon Tyne, UK	Peter Remmen, Moritz Lauster, Michael Mans, Tanja Osterhage and Dirk Müller	https://publications.rwth-aachen.de/record/684197	p1047.pdf
Comparison and Simulation of Building Thermal Models for Effective Energy Management	Smart Grid and Renewable Energy, 6, 95-112.	Amara, F. , Agbossou, K. , Cardenas, A. , Dubé, Y. and Kelouwani, S.	http://dx.doi.org/10.4236/sgre.2015.64009	SGRE_2015043016444093.pdf
Definition of a useful minimal-set of accurately-specified input data for Building Energy Performance Simulation	Energy and Buildings, Volume 165, 2018, Pages 172-183, ISSN 0378-7788	James Egan, Donal Finn, Pedro Henrique Deogene Soares, Victor Andreas Rocha Baumann, Reihaneh Aghamolaei, Paul Beagon, Olivier Neu, Fabiano Pallonetto, James O'Donnell	https://doi.org/10.1016/j.enbuild.2018.01.012	
Development of a Model View Definition (MVD) for thermal comfort analysis in commercial buildings using BIM and EnergyPlus	CITA BIM Gathering 2017, Construction IT Alliance of Ireland	Fawaz Alshehri and Paul Kenny and Sérgio V. Pinheiro and Usman Ali and James O'Donnell	https://researchrepository.ucd.ie/handle/10197/11018	2017_Fawaz_BIM-Gathering.pdf
Development of a Model View Definition for Environmental and Energy Performance Assessment	CitA BIM Gathering 2015	Pinheiro, Sérgio V, Edward Corry, Paul Kenny, e James O'Donnell	https://doi.org/10.13140/RG.2.1.4780.4248	DevelopmentofaModelViewDefinitionforEnvironmentalandEnergyPerformanceAssessment.pdf
Development of an Information Delivery Manual for Early Stage BIM-based Energy Performance Assessment and Code Compliance as a Part of DGNB Pre-Certification	Proceedings of the 15th IBPSA Conference:Building Simulation 2017, pp.2100-2109, San Francisco, CA, USA, 2017	Petrova, Ekaterina Aleksandrova, Iva Romanska, Martin Stamenov, Kjeld Svidt, e Rasmus Lund Jensen	https://vbn.aau.dk/en/publications/development-of-an-information-delivery-manual-for-early-stage-bim	Development_of_an_Information_Delivery_Manual_for_Early_Stage_BIM_based_Energy_Performance_.pdf
Development of openBIM-based energy analysis software to improve the interoperability of energy performance assessment	Automation in Construction, Volume 72, Part 1, 2016, Pages 52-64, ISSN 0926-5805	Jungsik Choi, Jihye Shin, Minchan Kim, Inhan Kim	https://doi.org/10.1016/j.autcon.2016.07.004	
Extending IFC to support thermal comfort prediction during design	2019 European Conference on Computing in Construction Chania, Crete, Greece, July 10-12, 2019	Fawaz Alshehri, Cathal Hoare, Usman Ali, Mohammad Shamsi, Paul Kenny, James O'Donnell	https://doi.org/10.35490/EC3.2019.203	Contribution_203_final.pdf

Appendix A – Academic and Industry Research References (continued)

Paper Name	Source / Publication	Authors	URL	File name (if available)
IFC BIM-Based Methodology for Semi-Automated Building Energy Performance Simulation	CIB-W78 25th International Conference on Information Technology in Construction, Santiago, Chile, July 15-17, 2008	Bazjanac, Vladimir	https://www.osti.gov/servlets/purl/938422	938422.pdf
IFC-Based BIM-to-BEM Model Transformation	Journal of Computing in Civil Engineering Vol. 34, Issue 3, May 2020	Ramaji, Issa J., John I. Messner, e Ehsan Mostavi	https://doi.org/10.1061/(ASCE)CP.1943-5487.0000880	
Information Delivery Manuals to Facilitate IT Supported Energy Analysis	Department of Civil Engineering, Technical University of Denmark (DTU), Kgs. Lyngby, Demnark	Thomas Fænø Mondrup, Jan Karlshøj, Flemming Vestergaard	https://itc.scix.net/pdfs/w78-2012-Paper-41.pdf	w78-2012-Paper-41.pdf
Information Delivery Manuals to Facilitate IT Supported Energy Analysis (Presentation)	CIB W078 2012 Conference : The 29th International Conference on Applications of IT in the AEC Industry - Beirut, Lebanon	Thomas Fænø Mondrup, Jan Karlshøj, Flemming Vestergaard	https://orbit.dtu.dk/en/publications/information-delivery-manuals-to-facilitate-it-supported-energy-an	CIB_PP_Paper_41.pdf
Innovations in Building Energy Modeling: Research and Development Opportunities for Emerging Technologies	National Renewable Energy Lab. (NREL), Golden, CO (United States), USDOE Office of Energy Efficiency and Renewable Energy (EERE), 2020	Roth, Amir, and Reyna, Janet	https://doi.org/10.2172/1710155	US_DOE_EERE-77835.pdf
Model View Definition for Advanced Building Energy Performance Simulation	Proceedings of CESBP / BauSim 2016 - IBPSA	Sérgio V. Pinheiro and Reinhard Wimmer and Tobias Maile and James O'Donnell and et al.	https://researchrepository.ucd.ie/handle/10197/11021	2016_Pinheiro_BauSim2016_FINAL.pdf
MVD based information exchange between BIM and building energy performance simulation	Automation in Construction, Volume 90, 2018, Pages 91-103, ISSN 0926-5805	Sergio Pinheiro, Reinhard Wimmer, James O'Donnell, Sergej Muhic, Vladimir Bazjanac, Tobias Maile, Jérôme Frisch, Christoph van Treeck	https://doi.org/10.1016/j.autcon.2018.02.009	2017_Sergio_Annex_MVD.pdf
New Generation Computational Tools for Building & Community Energy Systems: Annex 60 Final Report	International Energy Agency (IEA), Energy in Buildings and Communities Programme (EBC), September 2017, ISBN 978-0-692-89748-5	Michael Wetter and Christoph van Treeck	https://www.iea-annex60.org/downloads/iea-ebc-annex60-final-report.pdf	iea-ebc-annex60-final-report.pdf
Realizing openBIM: Development of a BIM Model View Definition for Advanced Building Energy Performance Simulation	Recknagel Online, 2017-01, European Commission - Seventh Framework Programme (FP7)	Wimmer, Reinhard; Pinheiro, Sérgio V.; O'Donnell, James	https://researchrepository.ucd.ie/handle/10197/11105	2017_Wimmer_GI_FinalWithImages.doc
Review of BIM's application in energy simulation: Tools, issues, and solutions	Automation in Construction, Volume 97, 2019, Pages 164-180, ISSN 0926-5805	Ehsan Kamel, Ali M. Memari	https://doi.org/10.1016/j.autcon.2018.11.008	
Technical Report: Literature Review concerning IFC, gbXML and CityGML data models for Energy Performance Simulation	E3D – Institute of Energy Efficiency and Sustainable Building, RWTH Aachen University, Germany, RWTH-2019-08837, Veröffentlicht auf dem Publikationsserver der RWTH Aachen University	Avichal Malhotra, Jérôme Frisch, Christoph van Treeck	https://publications.rwth-aachen.de/record/767468	767468.pdf
The Energy Application Domain Extension for CityGML: enhancing interoperability for urban energy simulations	Open geospatial data, softw. stand. 3, 2 (2018)	Agugiaro, Giorgio; Benner, Joachim; Cipriano, Piergiorgio; Nouvel, Romain	https://doi.org/10.1186/s40965-018-0042-y	s40965-018-0042-y.pdf

Appendix B – Building Energy Efficiency Standards / Protocols

This table documents the various national and international standards addressing building energy usage and efficiency. This includes mandatory and voluntary protocols and standards for assessing energy efficiency in a variety of project types both during design/project delivery of new projects and existing constructions.

Name	Organization	Jurisdiction
ANSI/ASHRAE/IES Standard 90.1-2019	American National Standards Institute (ANSI) American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) Illuminating Engineering Society (IES)	USA
ANSI/ASHRAE/IES 90.2-2018	-	USA
Bewertungssystem Nachhaltiges Bauen für Bundesgebäude (BNB)	Bundesministerium des Innern, für Bau und Heimat (BMI)	Germany
Building Research Establishment Environmental Assessment Method (BREEAM)	Building Research Establishment (BRE) Group	International
CasaClima / KlimaHaus	Agenzia per l'Energia Alto Adige / Agentur für Energie Südtirol	Italy
DGNB System	German Sustainable Building Council (DGNB e.V.)	Germany
DIN V 18599 (Series) - Energy efficiency of buildings - Calculation of the net, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting	Deutsche Institut für Normung e.V. (DIN)	Germany
EN 16247 – Energy Audits	European Committee for Standardization (CEN)	Europe
EN 16798-1:2019	European Committee for Standardization (CEN)	Europe
ENERGY STAR	US Environmental Protection Agency (US EPA)	USA
The Energy Performance of Buildings Directive of the European Union (EPB Directive 2018/844/EU)	European Union (EU)	Europe
EPIQR+ (Energy Performance, Indoor environmental Quality and Retrofit)	EPIQR Rénovation Sàrl + Estia	Switzerland
Green Globes	Green Building Initiative (GBI)	International

Name	Organization	Jurisdiction
International Energy Conservation Code (IECC)	International Code Council (ICC)	International
International Green Construction Code (IgCC)	International Code Council (ICC)	International
ISO 500xx Series (per ICS 27.015) Energy Efficiency. Energy Conservation in General	International Organization for Standardization (ISO)	International
ISO 520xx Series (per ICS 91.120.10) - Energy performance of buildings	International Organization for Standardization (ISO)	International
LEED	United States Green Building Council (USGBC)	International
Living Building Challenge (LBC)	International Living Future Institute (ILFL)	International
MINERGIE	MINERGIE	Switzerland
National Green Building Standard (NGBS)	Home Innovation Research Labs (HIRL)	USA
NFPA 900	National Fire Protection Association (NFPA)	USA
NFPA 5000	National Fire Protection Association (NFPA)	USA
Passive House	Passive House Institute (PHI)	International
Protocollo ITACA	Instituto per l'Innovazione e Trasparenza degli Appalti e la Compatibilità Ambientale (ITACA)	Italy
UNI TS 11300-1:2014 - Energy Performance of Buildings - Part 1: Evaluation of Energy Need for Space Heating and Cooling	Ente Nazionale Italiano di Unificazione (UNI)	Italy
UNI/TR 11775:2020 - Energy audits - Guidelines for energy audits of buildings	Ente Nazionale Italiano di Unificazione (UNI)	Italy
VDI 2067 (Series) Economic efficiency of building installations / VDI 2078 Calculation of thermal loads and room temperatures (design cooling load and annual simulation) / VDI 6007 (Series) Calculation of transient thermal response of rooms and buildings	Verein Deutscher Ingenieure (VDI)	Germany
VERDE	Green Building Council España (GBCE)	Spain
WELL	International WELL Building Institute (IWBI)	International

Appendix C – Building Energy Modelling Simulation & Analysis Engines

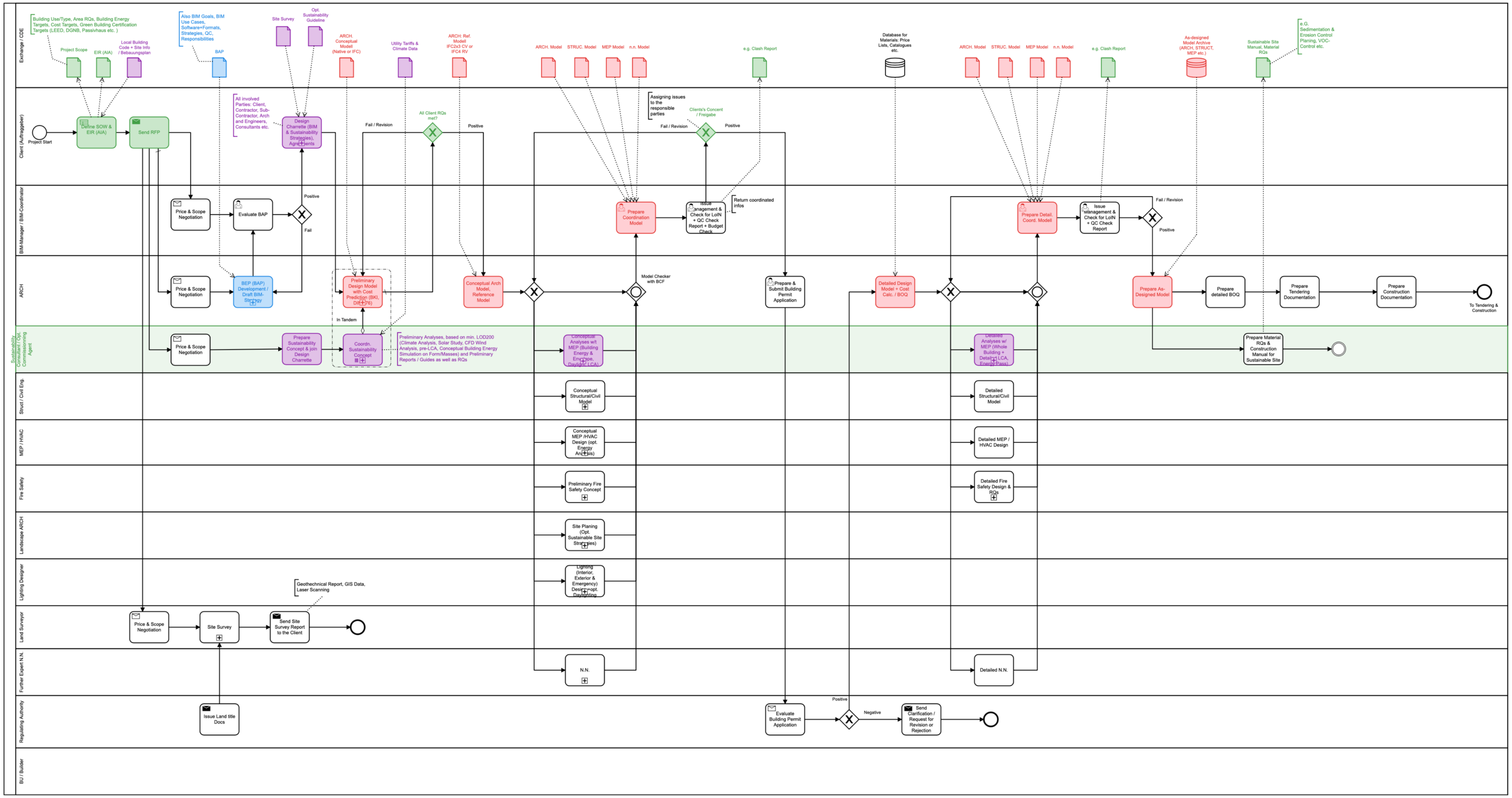
This table documents the major core technologies and methods used as the basis for BEM simulation and analysis. These engines may be common across different softwares but varying in user interfaces and detailed functionality. While not exhaustive, it documents many core technologies in national and international applications.

Name	Version	License	Developer	Applications
ApacheSim	6.1.3	Commercial (Proprietary)	Integrated Environmental Solutions Ltd., UK	IES-Virtual Environment (VE)
Carrier HAP	5.11	Commercial (Proprietary)	Carrier United Technologies, US	Carrier HAP
CENED+2.0	1.1.13	Commercial (Proprietary)	Azienda regionale per l'Innovazione e gli Acquisti S.p.A. (Aria S.p.A.)	CENED+2.0 Thermo Termolog
cove.tool	?	Commercial (Proprietary)	Cove.tool	Cove.tools
DOE-2	2.2	Freeware and Development	James J. Hirsch & Assoc. w/ LBNL, US	DOE-2 eQuest EnergyPro Green Building Studio (GBS)
Dymola	2022x	Commercial (Proprietary)	Dassault Systèmes	
EC700	11	Commercial (Proprietary)	Edilclima S.r.l.	EC7xx Product Series
EDSL Tas	9.5.2	Commercial	Environmental Design Solutions Limited, UK	Tas Engineering
EnergyPlus	9.6.0	Free and open source, BSD-style	Lawrence Berkeley National Laboratory (LBNL), US	DesignBuilder OpenStudio Autodesk Insight Sefaira Simergy TerMus PLUS For more...
ESP-r	?	Free and open source, GPL	University of Strathclyde, UK	ESP-r
IBP KERNEL 18599	4.99.375.0	Commercial	Fraunhofer-Institut für Bauphysik (IBP), DE	District Energy Concept Advisor Efficiency House Plus Calculator IBP:18599 (all versions)

Name	Version	License	Developer	Applications
IDA	4.8	Commercial	EQUA Simulation AB, SE	IDA-ICE IDA-ESBO
Modelica / OPENMODELICA	3.5 / 1.18.1		The Modelica Association	IBPSA Project 1
PHPP – Passive House Planning Package	9 or 10	Commercial	Passivehaus Institute, DE	PHPP
Spawn of EnergyPlus (SOEP)	0.x	Free and open source	Lawrence Berkeley National Laboratory (LBNL), US	
SOLAR-COMPUTER	05.26.01	Commercial (Proprietary)	SOLAR-COMPUTER GmbH	SOLAR-COMPUTER
SPARK	2.01	Freeware	Lawrence Berkeley National Laboratory (LBNL), US	VisualSPARK
TRNSYS	18	Commercial	University of Wisconsin-Madison, US	TRNSYS (via UW) TRNSYS (via TESS)
WUFI (US) WUFI (DE)		Commercial	Oak Ridge National Laboratory, US / Fraunhofer IBP, DE	WUFI (family of products) WUFI Pro WUFI 2D WUFI Light WUFI Plus WUFI Passive

Note that the International Building Performance Simulation Association – US chapter (IBPSA-US) also hosts and maintains the “Building Energy Software Tools (BEST) Directory” at https://www.buildingenergysoftwaretools.com/. Most of the entries are for end-user software for many different types of simulation and analysis workflows and capabilities, as well as building types. The BEST Directory also provides ratings, reviews, and updates to availability of a much larger list of software than this Appendix.

Appendix D – Example BEM Process Map for bSI Design Phase



Editor: Mirbek Bekboliev, M.Sc. buildingSMART Germany

Revision: 2020.03.27

Sources: 1) BIM Execution Planning Guide by Penn State CIC Research Team 2) Grundlagen und BIM-Gesamtprozess by BIM4infra2020 3) BIM-Methode im Planungsprozess der HOAI by AHO 4) HOAI 5) ISO 12006-2 6) Stufenplan Digitales Bauen

Abbreviations: RFP - Request for Proposal

This Process Map can also be found online at https://cawemo.com/share/c20aa8ef-1903-4c15-98f2-1b7dae7befd0

Courtesy of Mirbek Bekboliev, PEng., LEED GA, M.Sc. Building Science & Technical Project Manager at buildingSMART Germany

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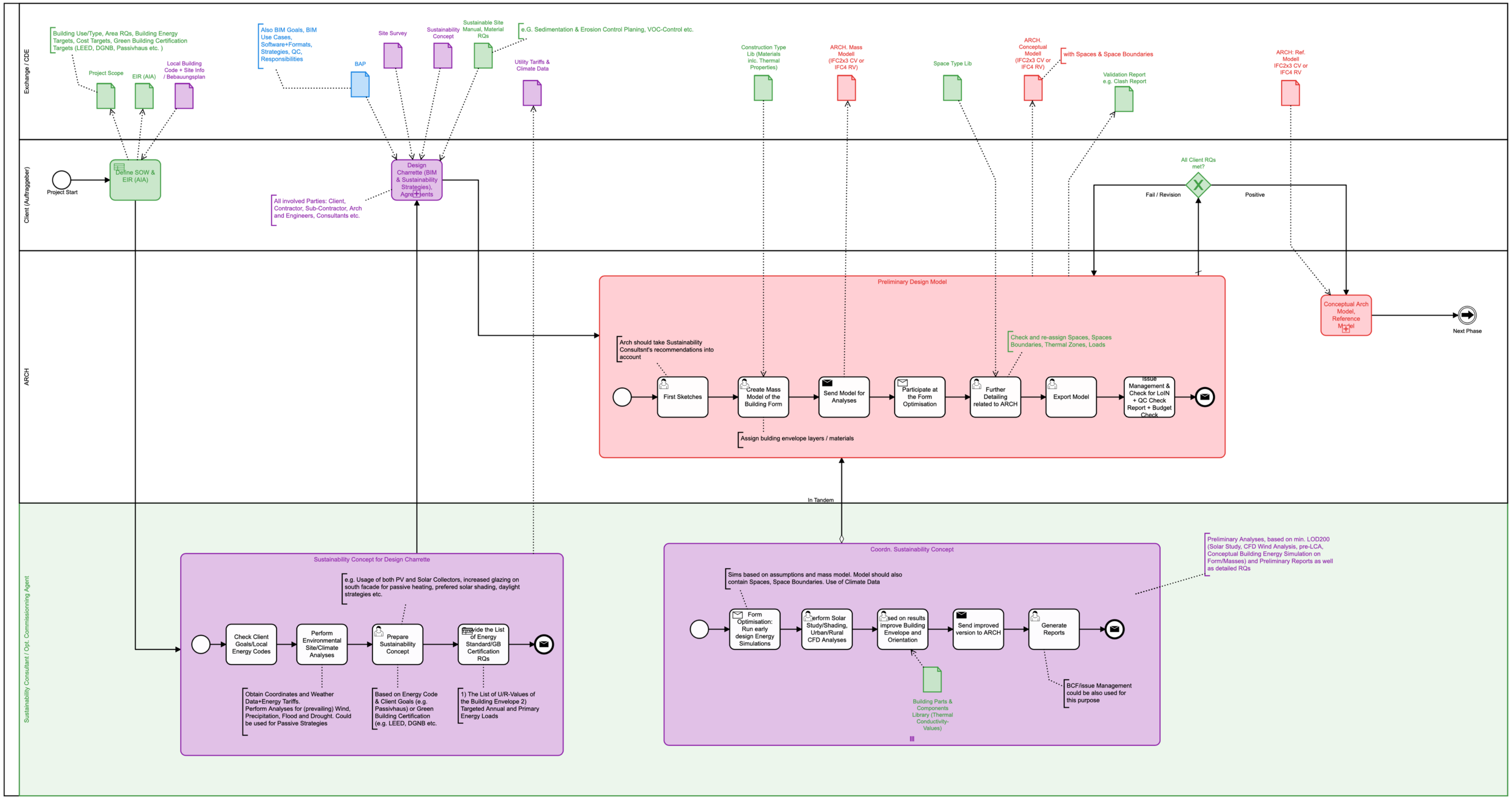
Appendix E – Example BEM Sub-Process Map for Preliminary Analyses



Editor: Mirbek Bekboliev, M.Sc. buildingSMART Germany

Revision: 2020.09.11

Sources: 1) BIM Execution Planning Guide by Penn State CIC Research Team 2) Grundlagen und BIM-Gesamtprozess by BIM4Infra2020 3) BIM-Methode im Planungsprozess der HOAI by AHO 4) HOAI 5) ISO 12006-2 6) Stufeplan Digitales Bauen

Abbreviations: RFP - Request for Proposal; SOW - Scope of Work; LoIN - Level of Information Needed; QC - Quality Control

This Process Map can also be found online at https://cawemo.com/share/88caafed-ecf8-4d93-86b9-55d333ef8c5a

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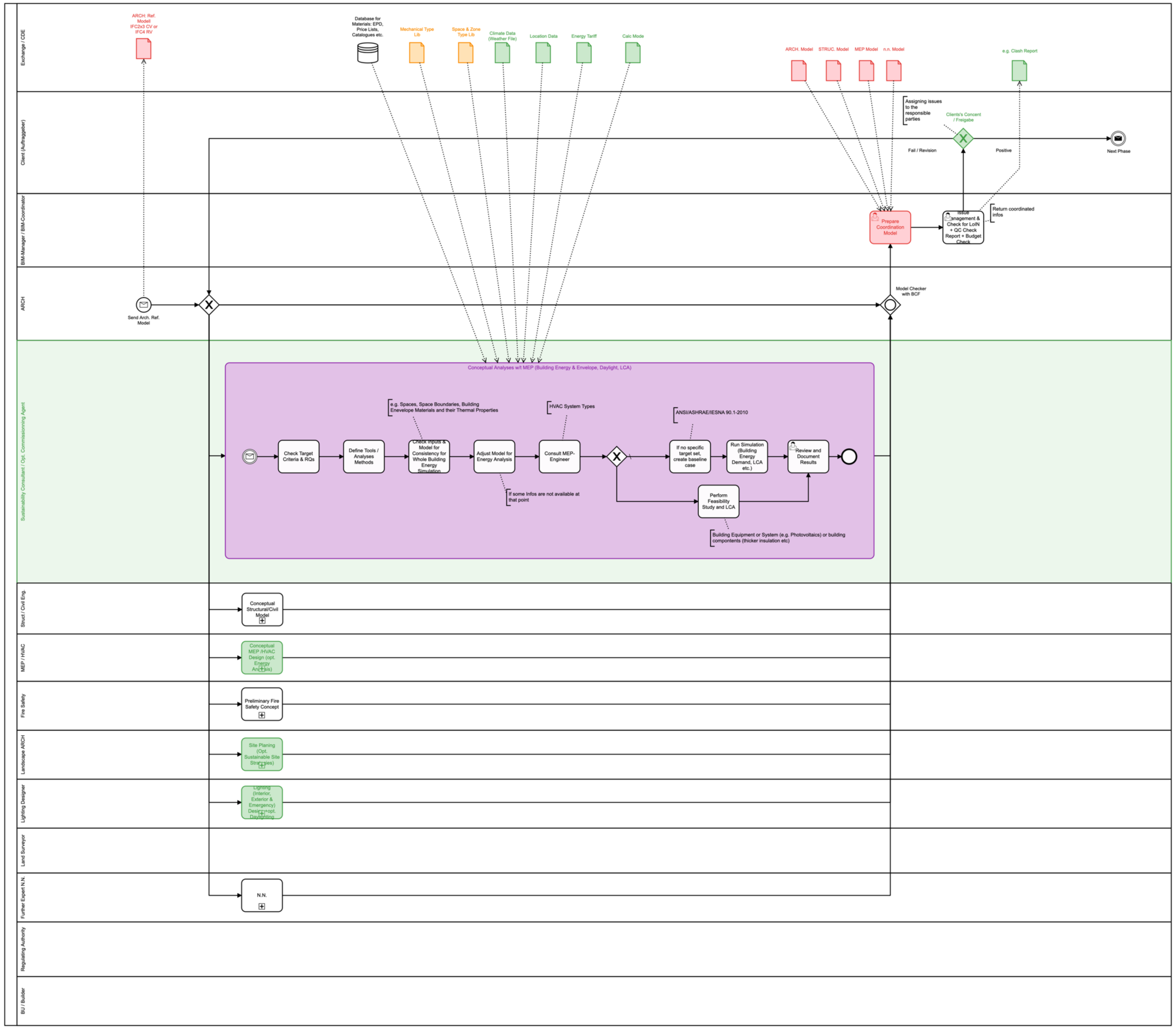
Appendix F – Example BEM Sub-Process Map for Conceptual Analyses



Editor: Mirbek Bekboliev, M.Sc. buildingSMART Germany

Revision: 2020.10.01

Sources: 1) BIM Execution Planning Guide by Penn State CIC Research Team 2) Grundlagen und BIM-Gesamtprozess by BIM4Infra2020 3) BIM-Methode im Planungsprozess der HOAI by AHO 4) HOAI 5) ISO 12006-2 6) Stufeplan Digitales Bauen

Abbreviations: RFP - Request for Proposal

This Process Map can also be found online at https://cawemo.com/share/df0e9fe9-4d09-489b-99f4-831902a16d18

Courtesy of Mirbek Bekboliev, PEng., LEED GA, M.Sc. Building Science & Technical Project Manager at buildingSMART Germany

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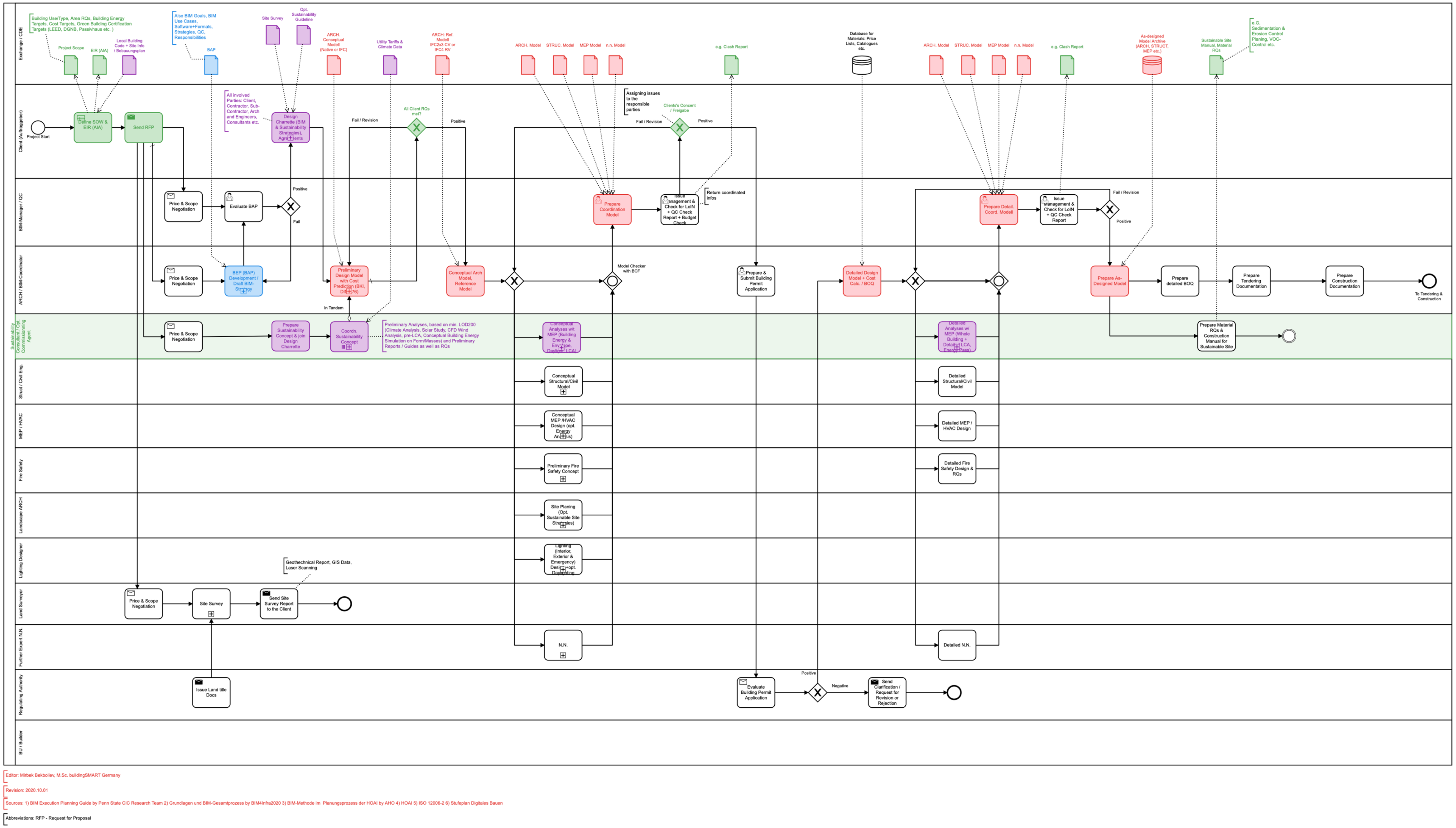
Appendix G – Example BEM Sub-Process Map for Detailed Analyses



This Process Map can also be found online at https://cawemo.com/share/fbd70c4e-a64e-455b-be55-5134f24199f2

Courtesy of Mirbek Bekboliev, PEng., LEED GA, M.Sc. Building Science & Technical Project Manager at buildingSMART Germany

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