Conceptualizing the FinDD API Plug-in: A Study of BIM-FM Integration

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HIGHLIGHTS

- The research presents a client driven application programming interface (API) 'software' plug-in 'FM intelligent design data' (FinDD) for Autodesk Revit as an entirely new and novel approach to BIM-FM integration.
- Participatory action research (PAR) reports on the specification of a client's bespoke COBie data requirements through the use of totems that visualise rich semantic FM data in 3D objects. Totems extend the use and application of COBie thereby minimising costs incurred by the FM team to update and maintain the as-built BIM.
- User group feedback and coding of their responses and requirements provided guidance on the functionality of the API plug-in and also afforded direction for future research.
- The FinDD API plug-in is an entirely novel approach to automating the input and retrieval of semantic FM data from the as-built BIM therefore, reducing the necessity to update/ create model geometry during the O&M stages of the development.
- This paper also challenges the standard COBie data drops and the spreadsheet format approach to integrating FM semantic data with as-built BIM.

ABSTRACT

This research paper reports upon a client driven approach to iteratively develop the FinDD application programming interface (API) plug-in. FinDD integrates building information modelling (BIM) and facilities management (FM) via the novel development and application of *totems*. Totems visualise rich semantic FM data in a 3D object to extend the use and application of COBie thereby minimising costs incurred by the FM team to update and maintain the as-built BIM. Participatory action research was used to develop the proof of concept and involved a study of two multi-storey, mixed-use educational buildings (with a contract value worth ≥ £150 million UK Sterling) located within Birmingham, UK. The lead researcher worked for the client's estates department and was instrumental in liaising with members of the project management team, synthesising their semantic data requirements and developing the FinDD API plug-in for Autodesk Revit. Research findings reveal that whilst FinDD was positively received as a bespoke extension of COBie (that was tailored to specifically meet client needs), further development is required to mitigate software inflexibility and augment automation of semantic data transfer, storage and analysis. Future work will validate the API plug-in via user experience and integrate additional databases such as post occupancy evaluations (POE).

KEYWORDS

Facilities management, building information modelling, application programming interface plug-in, totems, COBie

INTRODUCTION

The rapid pace of computerisation within the twenty first century has created a digital economy to effectively challenge the modern capitalist economy [26]. The digital age is maturing at an exponential pace and with it, the need for businesses and organisations to increase their capacity for adopting automated data driven decision making [21]. The digitalisation of modern organisations manifests itself from two key sources: i) the transformation effects of general purpose technologies (hardware) in the field of information and communication; and ii) the overwhelmingly vast inter-connectivity afforded by network based data and the internet [13]. Within a construction context, computerisation has the inherent potential to drastically change procedural methods employed for operating and maintaining buildings [20]. Such technological advancements have extended the decision support for strategic facilities planning, space planning, asset management and scenario simulation [42]. Throughout a building's life-cycle this procedural transition is further expedited by BIM technology [1]. BIM models are increasingly associated with multiple layers and sources of data/ information which extend beyond the model authoring tool capacity, namely: Building Automation Systems (BAS) [27] Computer Aided Facility Management Systems (CAFM) [6], System Information Model (SIM) [38], Electronic Document Management Systems (EDMS) [28] and Computerized Maintenance Management Systems (CMMS) [46]. BIM consequently assists the design team during inception but also proves itself invaluable to the facilities management team (FMT) during occupation [34;47;45;58]. Indeed, Boussabaine and Kirkham [9] reported that 80 percent of an asset's cost derives from the building's operations and maintenance (O&M). Maintenance is a necessity for sustaining the availability and reliability of a building's assets, which in turn ensures productivity for its operations and a safe working environment [5;3]. This is because BIM can provide an information conduit and repository (containing for example, manufacturer specifications and maintenance instructions linked to building components) in support of O&M activities [51] .

Rapid digitisation of building design and construction has impacted upon the later stages of building operation, most notably witnessed after the UK further developed COBie (Construction Operation Building Information Exchange) in 2014 to support its level two mandate [57;11]. COBie documentation together with BIM implementation promotes an opportunity for improved data hand-over for facilities managers and building owners [23;24]. BIM and facilities management (FM) integration (BM-FM) can be utilised for the building's O&M [2]. BIM can potentially support the integration of data from multiple perspectives within a digital environment that allows different stakeholders (i.e. structural engineers, architects, quantity surveyors, subcontractors) to share and exchange relevant information [33]. Yet in practice, over 70% of completed projects fail to provide a 3D model and corresponding COBie data set at the project's hand-over stages for the Client and facilities management team (FMT) [22]. Moreover, many practitioners consider that COBie provides universal coverage of all FM related parameters and fails to selectively filter what data is relevant to a building's bespoke O&M requirements [55]. Recent literature [6] also emphasized that: i) a BIM developed through design and construction often does not comprehensively provide the semantic FM information required at hand-over by the FMT. This is because although the client's O&M requirements are defined at the project's outset in the employer's information requirements (EIR); the relevance of this information to the facilities manager can be questionable leaving designers to second guess what semantic data will be usable during O&M; and ii) data within BIM for FM is not fully exploited for the decision support knowledge inherent within it, therefore, the opportunity to enhance a building's performance using rich semantic data is lost. Case studies of contemporary FM practice illustrate the amorphous range of services covered by FM and that data within BIM models created during design and construction do not necessarily take full consideration of those who use/ manage facilities during building occupation [4]. Moreover, databases that support O&M for the FMT often develop organically during building occupancy and use, and reside in disparate databases that are frequently underutilised and/ or lack interconnectivity [6]. This progressive growth of building data presents new opportunities for a deeper analysis of rich semantic O&M data that can support an informed Community of Practice (CoP) (consisting of the design team, contractors, FMT and building owners). For example, a building's operational performance data allows the CoP to develop optimised strategic maintenance plans. However, it also facilitates direct comparison between actual and predicted building performance thus proving invaluable to designers and contractors who seek to improve the performance of future building developments.

Given this contextual backdrop, this research reports upon the iterative development of the bespoke FinDD application programming interface (API) plug-in Autodesk Revit that manages semantic FM data in a BIM so that accurate cost estimations for building maintenance works can be produced using New Rules of Measurement (NRM3). This is achieved through the development of a *totem* that acts as a room-based data repository for FM. To develop this API plug-in, participatory action research was used to develop the proof of concept and involved industrial collaboration with a Client and FMT who funded and managed two multi-storey educational buildings located in Birmingham, UK. Associated research objectives are to: i) critically evaluate and report on state of the art data management tools and applications used to manage O&M knowledge in practice; ii) improve the efficiency and effectiveness of semantic building data capture, access and management via the API plug-in as a first step towards augmenting decision making for future O&M policies and procedures; and iii) enhance the financial efficiency of a building's O&M. Through research dissemination, the authors aspire to engender wider academic debate, challenge current thinking and contribute to the ensuing academic discourse by sharing contemporary and innovative developments within industry practice.

DISRUPTIVE TECHNOLOGY: AUTOMATION OF KNOWLEDGE WORK IN FM

Disruptive technologies were first defined by Clayton [19]; namely: new technologies having lower cost and enhanced performance measured by traditional criteria, which then relentlessly move up market, eventually displacing established competitors. McKinsey [43] predicts that *automation of knowledge work* will become the second largest disruptive technology over the next 10 years with an estimated 5-7 trillion dollar impact across a wide range of industry sectors. Knowledge work tools can reduce costs by helping organisations improve efficiency, but they can also substantially raise standards by delivering a fast, consistent and high-quality customer service [48]. Consecutive knowledge worker tasks can be automated through sophisticated analytics tools [43]. This potential generates openings for radical change in the way that 21st century businesses and organisations operate [52].

Within the Architectural, Engineering, Construction and Owner-operated (AECO) sector, early signs of automation of knowledge work are evident through BIM adoption which affords a digital environment to store, share and integrate information for future use [53]. BIM represents a new disruptive technology that has significantly decreased the number of manual processes involved previously in the design stages of construction [59]. It enables extensive stakeholder collaboration between the various parties to the construction contract (during the design and construction phases) via a single integrated model [4]. Consequently, new knowledge and insight can be gained in design feasibility prior to construction commencing. Despite the many palpable benefits of BIM application during the design and construction stages, case-studies of its application during the O&M stage of building occupancy remain scant [35;6]. The inherent value of BIM-FM integration is derived from improvements to: current manual processes of information handover; accuracy of, and accessibility to rich semantic FM data; and efficiency increases in work order execution [34;6]. From an operational perspective, BIM can embed key product and asset data, and generate a three-dimensional computer model that can be used to improve information management throughout a project's lifecycle [32]. Therefore, BIM deployment is invaluable to organisations that seek to obtain greater value from the technology [39;40]. However, capturing the ever-growing data requirements of buildings for FM is a complicated process because delivering efficient O&M is contingent upon information generated within a digitized 3D BIM and the effective synthesis and utilisation of complex/ voluminous data [44;7]. An additional issue is the failure to capture relevant data for O&M; instead designers tend to focus on the production of geometry during the design and construction phases. This issue has often been attributed to a poor client brief and/ or building specification [18], particularly in relation to late engagement of the FMT [40].

BIM data requires a structured method of information categorisation that can be tracked, validated and extracted [25]. However, within a multiple collaborative stakeholder BIM environment, the model-related information is rapidly assimilated and becomes more difficult to manage. Boton *et al*., [8] speculated that *"the management of raw data (e.g. from BIM as well as from other sources) is not really conceptually formalized so far."* Others have argued that many of the information related issues only focus on data-interoperability. For example, Grilo *et al*., [29] argued that BIM should create a broader base for interoperability in order to be fully utilisable, which should include standards on communication, coordination, cooperation and collaboration. Whilst specifications such as PAS 1192-3 [12] provide a framework to support BIM enabled FM, there still remains little guidance on how to translate this standard into practice. The proliferation of data accumulated with as-built models[1], much of which is peripheral during the O&M phase, becomes a matter of concern for the FMT in terms of extracting critical and relevant information and knowledge [38]. To further exacerbate this issue, not all data are contained within one federated model, with the FMT often linking additional relevant external databases to the BIM to create an enormous integrated multi-dimensional model [56;38]. This rapid and organic expansion of accumulated and stored building data means that *semantic data analytics* in the FM sector is essential if palpable O&M cost benefits are to be realised. However, generating meaningful decisions from this vast pool of complex data is increasing challenging for the FMT and building owners [50]. Hence, the need for automated work knowledge using computerisation.

HARNESSING THE VALUE FROM SEMANTIC DATA FOR FMT

Lee *et al*. [37] identified eight information dimensions which can be managed within a BIM during a building's life cycle. These dimensions are: i) maintenance needs; ii) acoustics; iii) process; iv) cost; v) energy requirements; vi) crime deterrent features; vii) sustainability; and viii) people's accessibility. This eclectic mix of data requires highly structured object-orientated modelling techniques to engender creative thinking within the FMT [7]. For example, Matthews *et al*. [41] , explored adaptation of cloud-based technology with object

[1] As-built models in this context represent a building as constructed vis-à-vis the original building design as conceived and prescribed by the architect, engineer and/ or designer. The as-built model typically evolves during the construction and in-use phases of a building's life cycle.

oriented workflow for as-built BIM scheduling. Similarly, new object-orientated modelling techniques adopted in tandem with semantic data analytics can be utilised in the O&M stages (Oskoiue *et al.,* 2012). Many benefits associated with BIM-FM integration relate to data accessibility for O&M purposes, but as the building evolves, so does the complexity of historical data (*ibid*.). Harnessing data for analysis in FM represents a new shift in the way pro-active maintenance has formerly been prescribed in the sector. Rigorous data analytics have already been successfully applied in other industries driven by the potentially huge cost savings on offer [14]. A building's O&M could reap similar benefits. The extant literature is replete with cases justifying data analysis for O&M; these include: FM Visual Analytics System (FMVAS) for failure [45]; visual approach for maintenance management [16]; object-oriented method of asset maintenance management [30;31]; 'Visualizer'- decision-support tool for service life prediction [36]; and knowledge-based BIM (K-BIM) developed on the basis of as constructed information of the facility used to enhance an FM organisation's competitive advantage [15]. However, whilst previous research has predominantly focused upon specific and individual O&M tasks, there remains a notable shortage of holistic guidance that encapsulates all O&M related information for decision making purposes. Case studies of exemplary practices are therefore urgently needed at the O&M stage to demonstrate the potential value harnessed from semantic data analysis with BIM.

RESEARCH DESIGN AND APPROACH

The research design employed participatory action research (PAR) (cf.[17;54]) to produce a client driven application programming interface (API) 'software' plug-in (FinDD). Although PAR has many progenitors, it can be broadly classed as collective self-experimentation amongst participants that is augmented by evidential reasoning (*participation*), fact-finding (*action*) and learning (*research*) (cf. [49;12]). Two multi-storey educational buildings provided the basis for this research inquiry and were designed and constructed consecutively in Birmingham, UK over an 18 month period (refer to Figure 1). The contract value was worth ≥ £150 million UK Sterling and created 100,000 sq ft of new office space; albeit future plans seek to expand the development further. The lead researcher collaborated directly with the building's estates team (who coordinated project management and acted as the client's representative) but also engaged with all parties within the Project Management Team (PMT) to gather project information through liaising with each stakeholder. The PMT included the client's representatives (i.e. the Building's Estates Department) and design related disciplines (including the BIM Process Manager, the lead Architect, Contractor's Construction Manager, the Contractor's BIM Manager, Principle Designer for Mechanical Engineering and Plumbing and the Lead Structural Engineer). Note that the Estate's Department held four fundamental roles, namely that of: client's representative; BIM process manager; project manager; and Estates Department and consequently, covered all three major phases of the building's life cycle.

In operational terms, a five stage process was adopted for the development of the FinDD API plug-in for Autodesk Revit, namely: s*tage one: development of the totem*. Totems act as a virtual repository that synthesised all relevant information sources into one integral area, usually a room, for ease of access; *stage two: development of the asset information matrix (AIM)*. This phase was instigated during the design, construction and use of the first building. It specifically sought to identify relevant semantic data and information sources from PMT members and strategies for integration into the totems; *stage three; development of the FinDD database representation*. The data sources identified in stage two were bi-directionally linked to the totems via the plug-in to allow changes to be updated in the model; *stage four: conceptualising the enterprise application*. Members of the PMT defined their user requirements of FinDD; and *stage five: back-end and front-end software development*. Object classes and their functionality were defined (back-end development) and a graphical user interface (front-end development) was designed. The API plug-in development process was iterative with each iteration taking into account client driven aspirations, stakeholder experience and user feedback.

The primary qualitative data, was collected through seven 'focus group' project team meetings held over an 18 month period (January 2015-June 2016) and was supplemented by phone calls and emails to afford additional clarification when required. Secondary quantitative data sources further complemented information obtained and consisted of project documents including BIM execution plans (BEP), employer's information requirements (EIR's) and project execution plans (PEP). These archival records of project BIM documentation and contracts provided: i) an account of current practices through the exploration of stakeholder expectations; and ii) collaborating organisations with opportunities to learn from everyday experiences of PMT stakeholders.

FIVE STAGES OF FINDD API DEVELOPMENT: DISCUSSION AND FINDINGS

At the outset of the development, some of the PMT group members were inexperienced at utilising BIM technologies. However, as building one progressed and team confidence grew, the idea for the FinDD API plug-in was conceived and proficiency/ competency gains were secured in building two. This iterative process enabled: the PMT group to mature as a collaborative partnership; individual parties to avoid unnecessary dispute(s); and both buildings to be constructed to all parties' satisfaction. Efficiency gains were also made by individual PMT members who acquired new knowledge that allowed them to streamline project management and reduce costs without adversely impacting upon quality. For example, the Architect who employed ten people during building one, reduced their team to five people for building two by learning how to optimise the production of drawings with BIM. A Principal Architect said: *"One of the bigger benefits that we've learned going into phase II is how to keep drawing sets coordinated and segregation of the model into work-sets*[2]*, and split the model into groups and layers so that we don't produce a single drawing and come back to it as we did before with AutoCAD - in that sense we have become a lot smarter with how we model with BIM."*

These five aforementioned stages of the FinDD API-plug-in development are now discussed in further detail; the ensuing narrative is complemented with pertinent feedback from members of the PMT to provide additional insight.

Development of the totem

When formulating the totem concept to ensure BIM-FM data integration, the PMT considered the data requirements for FM and model structure for data retrieval. The ambition was to generate a totem that would deliver interoperability and encapsulate the following attributes: i) increased coordination between the contractor and design team stakeholders during model development; ii) enhanced communication between project stakeholders; iii) informed decision making; and iv) ease of navigation within the cloud-based BIM model. In practice, each individual totem holds all relevant semantic FM data that is pertinent to that particular space (including room finishes, services, lighting and frequency of maintenance). As this was not a government funded project development and building one was under construction prior to 2014, the use of COBie was not mandatory, although the data

[2] A 'work-set' is restricted collection of building objects (i.e. walls, doors, floors, stairs, etc.) which may be edited by one user at any given time.

requirements and model structure of the API plug-in were heavily informed by the COBie standard. The client demanded that all members of the PMT use Autodesk products when developing the models in an attempt to overcome interoperability issues. The totem was conceived and developed to extend the functionality of the room object in Autodesk Revit, as the ability to embed and link rich semantic FM data at this level was fundamental to the FMT and client requirements.

The different PMT members each added room specific information into the totems; the contractors were then able to retrieve asset related information for guidance during construction and attach progress photos to each totem. The totems themselves connected to multiple external databases which provided access to room specific O&M manuals, maintenance frequency codes for different spaces and product fact sheets.

Asset information matrix and totem integration

The totems' information requirements were defined in the asset information matrix (AIM) and semantic FM data within the AIM was classified according to the NRM3 standard. Utilising the NRM3 standard assisted the FMT with cost estimation and cost planning for building O&M works. Semantic data was input into the totem by design team members according to the AIM for the various stages of development (i.e. RIBA 'plan of work' stages 3-5) and corresponding to data drops 3, 4 and 5 in COBie. Figure 2 illustrates the schematic design to achieve information feed (via totems) at all three stages of the buildings' life cycle (namely: i) design/ pre-construction; ii) construction and commissioning; and iii) as-built/ post construction). Two interlinked BIM cloud models are apparent. The first model contains three separate models that cover architectural, structural and MEP 3-D models that are merged into one federated model (e.g. pipes, services and structural elements). This federated model was used for: avoiding clashes; facilitating 4D and 5D modelling; and providing a single point of truth, accessible via the cloud, where totems could be linked and updated. The second cloud database includes additional information and resources such as photographs of progress on site during construction works, notes taken on programme of works and mark-ups of any amendments or 'BIM snags' that were required within the BIM model itself. The contractor then monitored and managed these data drops into the totem on a weekly basis from the federated model. The cloud based BIM and totem data was managed by the contractor on site but was created by the estates management team on the client's behalf. Totems were gradually populated throughout construction to provide a complete and accurate record of the as-built development. Other documents not directly related to the BIM (such as equipment fact sheets, O&M manuals, documentation and drawings) were linked into the cloud based federated model via the totems. The cloud database was also populated by the estates management team and design teams who recorded a snagging list of defects and any remedial actions required. A laser scan was then conducted which was then compared to the as-built BIM model. Currently the estates and research team are exploring ways in which Building Management Systems data (as an external source of data) will be linked via totems into the cloud based model.

Development of the FinDD database representation.

Figure 3a presents a schematic representation of the databases that were integrated within the totem; whilst Figure 3b illustrates FM parameters contained within an individual totem (for example, project documentation (including: BEP; PEP; EIR; and AIM). Within the federated cloud model, databases that contain tasks, checklists, embedded data and snags are complemented with other external databases that are linked to the totem via a URL link to the client's *Sharepoint*. Sharepoint represents a secure on-line open access repository and storage area that is populated by an ecliptic range of pertinent business information and resources including project documentation. Password protection within Sharepoint restricted PMT members' access to relevant data only thus preventing them from accessing other more sensitive business intelligence that was unrelated to this development. Typical data accessed by the PMT on Sharepoint included photographs of the development, O&M manuals, reports and drawings. A senior member of the PMT said: *"We have the NRM3 classification in our models, breaking all the O&M costing down in the models component by component. These all link to the maintenance codes, SFG20*[3] *which is the standard maintenance frequency code. This was implemented as a result of the mandate where RIBA [Royal Institute of British Architects] and RICS [Royal Institute of Chartered Surveyors] are requesting the use of NRM3 coding instead of the typical UniClass format. Essentially what we will have is an output of models that are all aligned to the NRM3 as well as O&M documentation which is similarly aligned to the NRM3 coding. So we have a direct relationship between object and the O&M documentation for that object. The maintenance codes work in such a way that we can go from object through to maintenance code - we can do this for all our objects and we*

[3] SFG20 Standard Maintenance Specification for Building is developed to help customize maintenance regimes for building owners and clients.

can start planning simultaneously the maintenance procedures for each space, which will allow us to bring in the asset list into a system and it will tell us the maintenance required during its lifetime."

During development work, three other external databases were ear-marked for future integration into the information totem (refer to Figure 3a). These databases were: the building management system (BMS) to control and monitor the building's mechanical and electrical equipment; student attendance monitoring (SAMs) to gain insight into how the building was being used by occupants; and SITS to assist in both course and student management. During the O&M phase, the client utilised room barcodes to aid the management of assets by allowing cost-effective access to totem data via mobile devices (i.e. tablets) by scanning room barcodes (refer to Figure 4). Each barcode was bi-directionally linked to corresponding room based totems in the as-built BIM thus enabling the FM semantic data to be mapped into any CAFM software utilised at the later stages of the development.

Conceptualising the enterprise application.

During the PMT focus group discussions that sought to determine user requirements/ functionality, four main lessons emerged regarding the use of BIM and totems during the project, namely: i) *the creation of totems*; ii) *limitations of a semi-automatic totem*; iii) *inflexibility of software providers*; and iv) *lack of software integration*. First, totems were originally conceived and adopted towards the end of building one when the estates management team realised that FM requirements (such as building heating and cooling loads, and building usage) could have been uploaded into the BIM at the design stage to inform the design and better meet client expectations. A MEP designer said: *"Design data, such as ventilation rates, cooling loads could have been included in the design stages already, as the M &E contractors are often playing catch up from the other design team…"* Second, it was apparent that the totems developed were not fully automated and hence, as changes to specification occurred, manual updates were needed in the model. For example, when the contractor altered a specification provided by the Architect or MEP designer (at the construction and commissioning stages). The contractor stated: *The totems still lacked automation, what would have been good was to have a live feed of the changes in the model with the totems, as they currently did not capture all of the changes in the model, some information had to be manually added to the totems…"* Third, the BIM software designers (as external providers) were unwilling to implement bespoke modifications and amendments to their software. For example, information could not be exported into other file formats for usage in room data sheets or for snagging lists post construction. A BIM Manager said: *"We were unable to export the totem information directly out of the software into a PDF, which could then be used as a room data sheet…"* Fourth, the BIM model structure had a distinct lack of software integration capability and therefore, when accessing the totem corresponding room elevational views were inaccessible and had to be extracted from other databases of drawings within the BIM model. A Project Manager said: *"What would be useful is if we could have direct views of reflected ceiling plans, room elevations and floorplans just by clicking the totems faces, makes it easier to then share the model with subcontractors…"*

Verbal and written responses were subsequently noted and then categorised into A*n*, B*n*, C*n*, D*n*, E*n* and F*n* bandings for brevity by the research team (refer to Figure 5 and Table 1). Once these bandings were established, they were presented back to group members for sign-off approval before the API was developed further in the BIM authoring tool Revit. This stage in the process was particularly important because it illustrates early development stages of the plug-in and object classes, and how the functionality of Revit was extended to suit user requirements for the totem.

Back-end and front-end software development.

Figure 6 presents a graphical illustration of the Revit user interface for the plug-in and describes Revit add-in functionality. The object class diagram presents a schematic of the functionality and behaviour of these add-in files for Revit. For example, button two informs users how many rooms include a totem within the room; where all classes connect to the object class which represents the totem. Figure 7 presents the front-end graphical user interface of the FinDD plug-in developed. At this juncture, FinDD represents a proof of concept that demonstrates its feasibility; further development and expansion is now planned and will include naming buttons to better describe functionality to future users who are less familiar with its development. When reflecting upon the development and FinDD, a representative from the Estates Department said: "*Building two has been one of most successful BIM project in our business, it has really pushed BIM all the way through the process right through to FM, and we haven't actually done this on any other project to date. Possibly in the future we could benefit from having a direct feed of BMS data, and live Post Occupancy Evaluation (POE) fed into the totems to inform architects and the FMT on how the occupants are responding to the new building."*

CONCLUSIONS

The extant literature is replete with recommendations for far greater BIM-FM integration as a means of producing accurate design data (both geometric and semantic) for handover to the building's client. Importantly, this integration presents an ideal opportunity for data retrieval and use during the O&M stages of building occupancy. Yet to date, case studies of practice-based initiatives are scant or provide rudimentary insight into the myriad of opportunities available to clients and the building's facility management team. This is most likely due to two fundamental reasons. First, computerisation technology is developing at an exponential pace and hence, keeping abreast of the latest knowledge and developments presents a major challenge for both industry and academia. Second, securing access to large construction project developments means consequential data generated with an as-built BIM is a hugely complex and difficult task and only achievable with a client's approval. Even then, legal contracts covering data disclosure, copyright/ ownership rights and data protection can lead to exorbitant costs being incurred by a research team and delays to secure agreements with all parties concerned. The extant literature on BIM-FM integration also points to the specific limitations of data integration between BIM and FM related data authoring platforms, as well as the lack of standardised methodology for such data transfer.

Fortuitously, a proactive client and project management team who acknowledged the benefits of collaboration with academia assisted this research. Given their invaluable insight and support, the FinDD API plug-in and the integral FinDD totem were first developed and then enhanced through the development of an API (proof of concept) in the BIM authoring tool Revit; where the innovative use of the FinDD totem represented a bespoke adaptation of 'COBie data drops' to suit the client's needs. At each incremental stage of the developmental process, limitations and applications of FinDD were categorised under the guise of future work. Such work includes: addressing software inflexibility within the FinDD totem and implementing automatic data analytics; validating the API plug-in via user experience; and integrating additional databases into the totem such as post occupancy evaluations (POE). Each extension of FinDD will continue to pose unique challenges and opportunities but as other bespoke API plug-ins emerge from the literature, the likelihood that a hybrid plug-in is developed increases; such will yield broader appeal and improved software upgrades.

Regardless of future developments, FinDD also allows an invaluable feedback loop/ of building performance when compared against the designer's original estimation. Live feed sensor data used by the building management system (BMS) on building usage fed into the totem will facilitate a better visual understanding of building performance and usage for the client and FMT. Observations accrued from the case study have also shown how an object orientated workflow can provide structure and develop complex as-built BIM models whilst embedding key O&M related information. These inherent attributes of FinDD will provide openings for clients and members of the PMT to learn from developments, improve their performance and reflect upon how future technological advancements can further enhance a building's performance.

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Figure 1 – Buildings one (Parkside - left) and two (Curzon - right) image courtesy of Wilmott Dixon.

Figure 2 – Adopted from the original BIM execution Plan for Building II

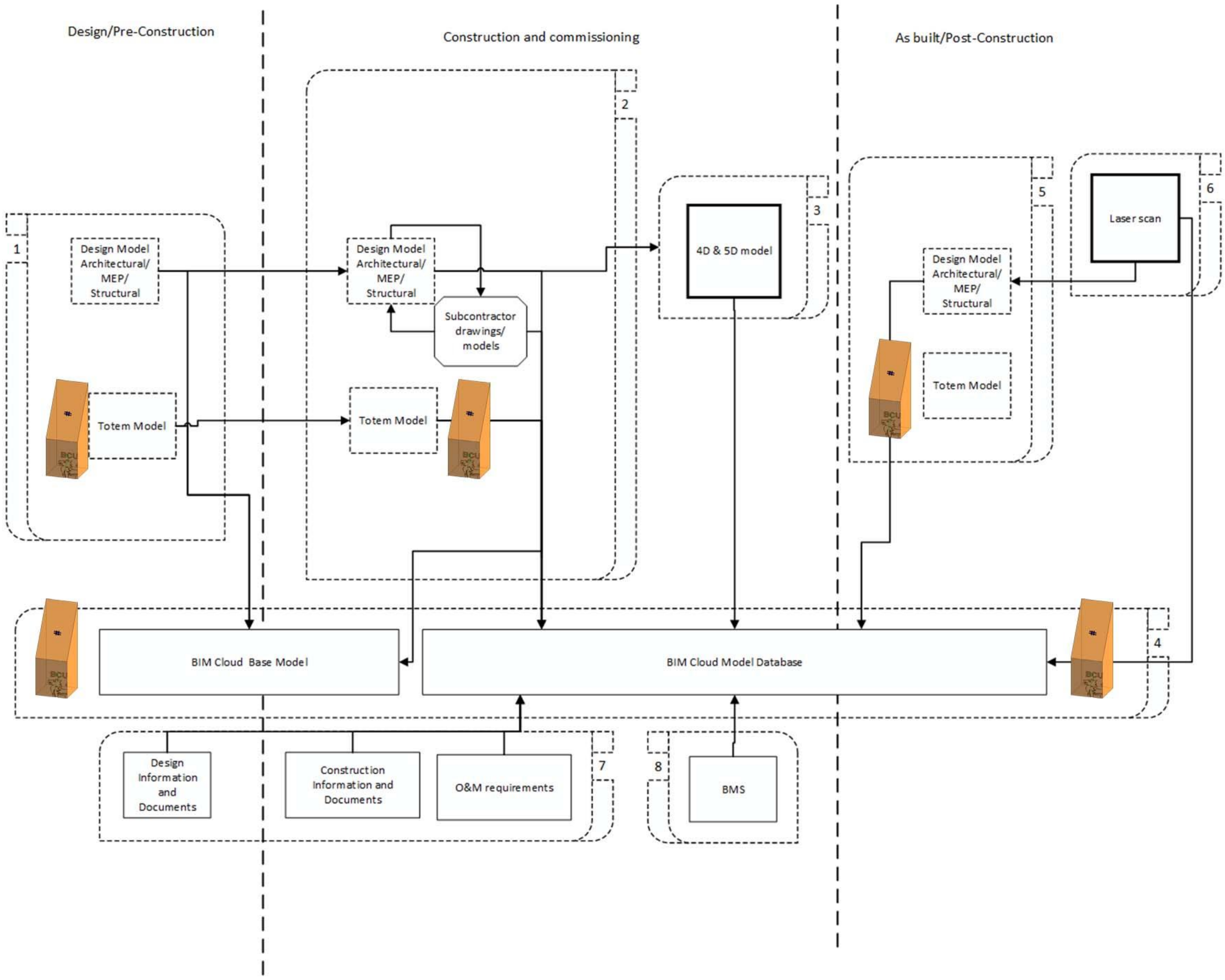


Figure 3a – Schematic database representation for FinDD

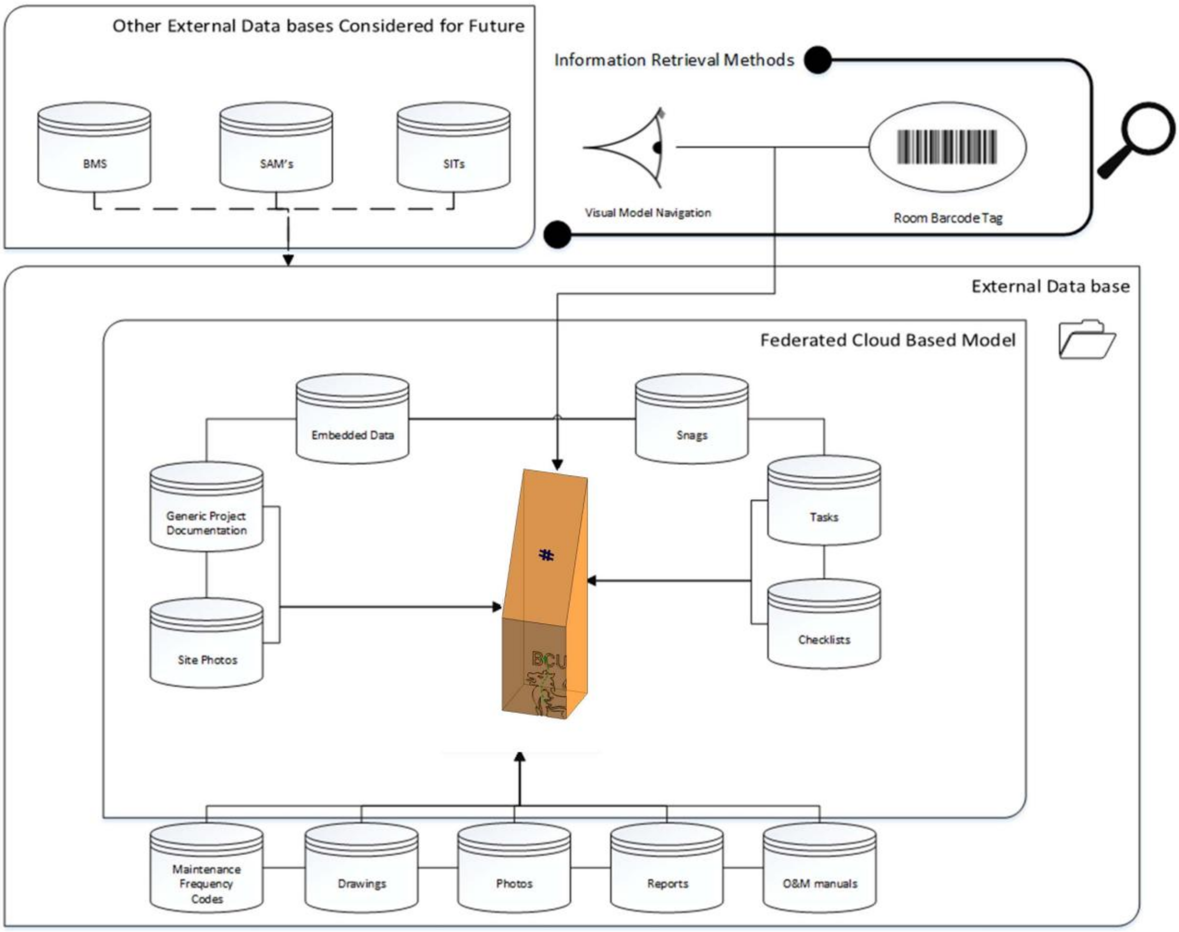


Figure 3b – FM parameters embedded within the totem

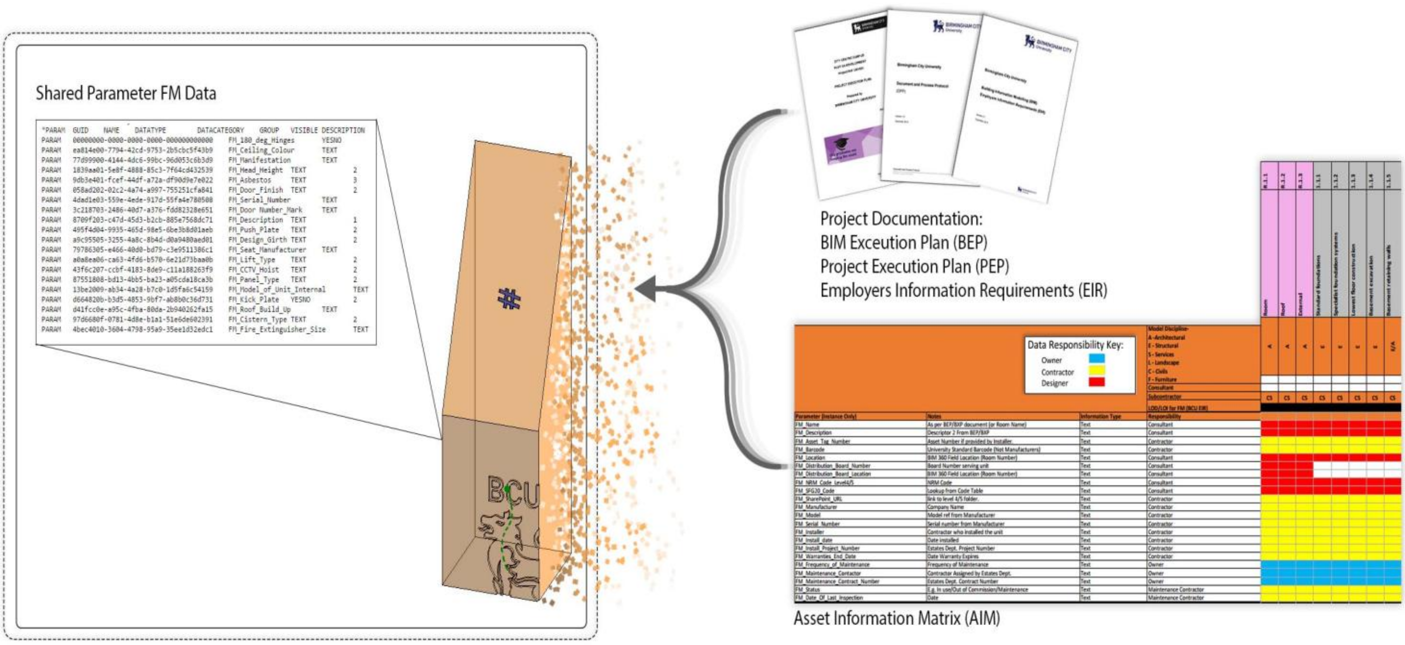
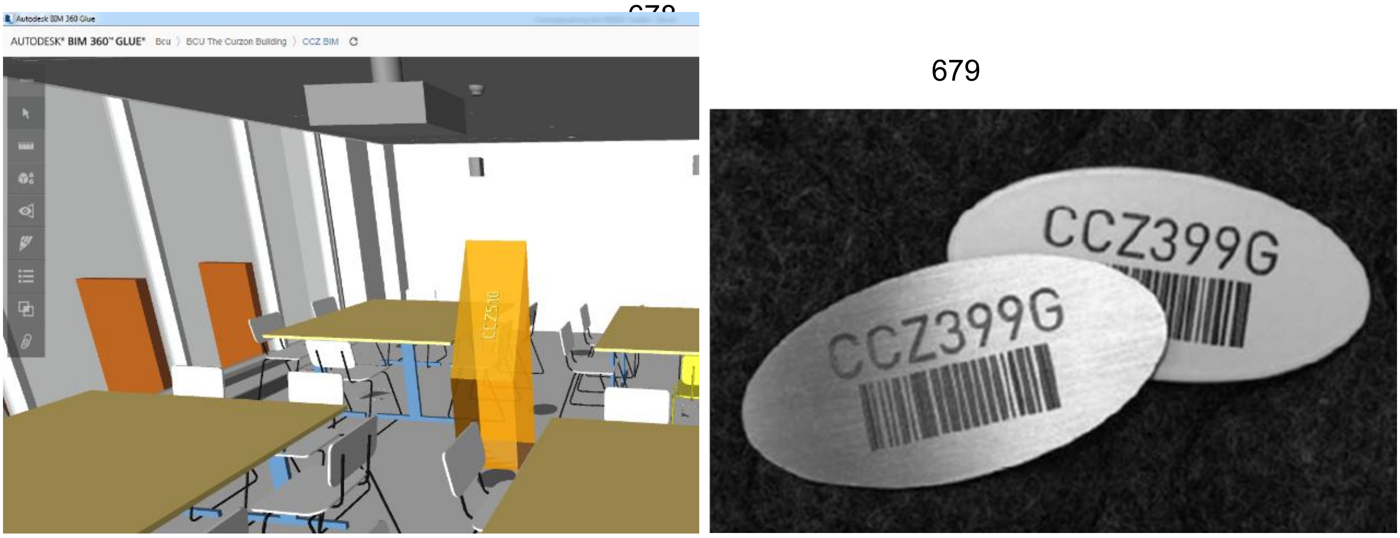


Figure 4 - As built-BIM used for asset data access and retrieval via the totem



a) b)

a) View of the as-built BIM model; b) Asset management with room barcodes.

Figure 5 - Conceptualisation of enterprise application FinDD API

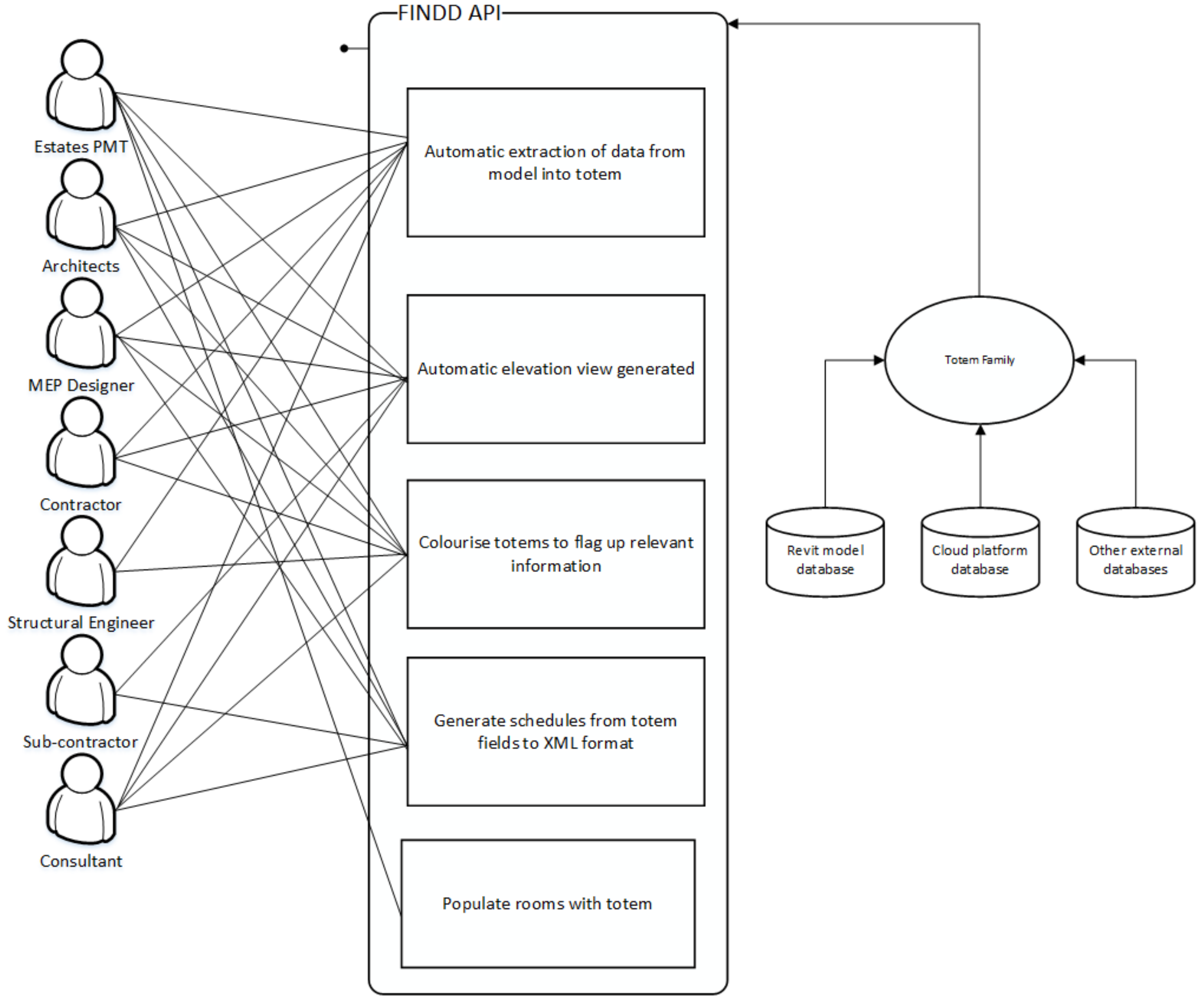


Table 1 – User group feedback and coding of the narrative

User group functionality request	Coding for the API	Stakeholders	Stakeholder Freq.
Automatic extraction of data from the model geometry (e.g room volume, area).	A_1	ED, CM, AR, MEP, SE, SC, C	7
Automatic update of the totem following BIM progression/ changes.	A_2	ED, CM, AR, MEP, SE, SC, C	7
Automatic generation of heating and cooling loads n/s/m^2 from model data.	A_3	MEP, C	
Automatic identification of ductwork and pipework data from model.	A_4	MEP	1
Remove manual data input into totems to reduce errors and duplication of work.	A_5	ED, CM, AR, MEP, SE, C	6
Automatic elevation views are created when a totem is placed into a room and those views should be accessible from the totem.	B_1	ED, AR, MEP, CM, SE, C, SC	7
Colourize totems to flag up relevant information (i.e. health and safety related information).	C_1	ED, CM, AR, MEP, SE, SC, C	7
Generate schedules and room data sheets into Extensible Markup Language (XML) format.	D_1	ED, MEP, AR, CM, SE	5
Populate rooms without totem automatically.	E_1	AR, ED, CM, MEP, SE	5
Access to laser scanned point cloud data via the totem possibly via external URL link to another database.	F_1	CM, ED,	2
Design briefing information existing in FinDD as guidance at design stages i.e. target area for guidance.	F_2	AR, ED	2
Track changes in the totem (i.e. historical input data).	F_3	ED, CM	2
Health and safety issues linked.	F_4	CM	1
Dynamic link for calculations (i.e. heating and cooling loads).	F_5	MEP, AR	1
SFG20 maintenance schedule codes linked into totem.	F_6	ED	1
Post-construction O&M: Post occupancy data integration. To learn from design and feed back to relevant design stakeholders.	F_7	AR, ED,	2
Register of outstanding items integrated into totem at handover stages.	F_8	CM, ED	2
Totems to be live in BIM 360 Glue (reduce the need to upload new versions).	(N/A for proof of concept)	ED, CM, AR, MEP, SE, SC, C	7

Coding API Key:

A_n. Automatic extraction/ update/ input of data from the model into the totem; B_n. Automatic elevation view generated; C_n Colourize totems to flag up relevant information; . D_n Generate schedules from totem fields to XML format; E_n Populate rooms with totems; and F_n Future work – currently under construction.

Stakeholder Key:

ED. estates department; CM. construction manager; AR. architect; MEP. mechanical electrical plumbing designer; SE. structural engineer; SC. sub-contractor; and C. consultant.

Figure 6 – Back-end development (Revit user interface and object class diagram)

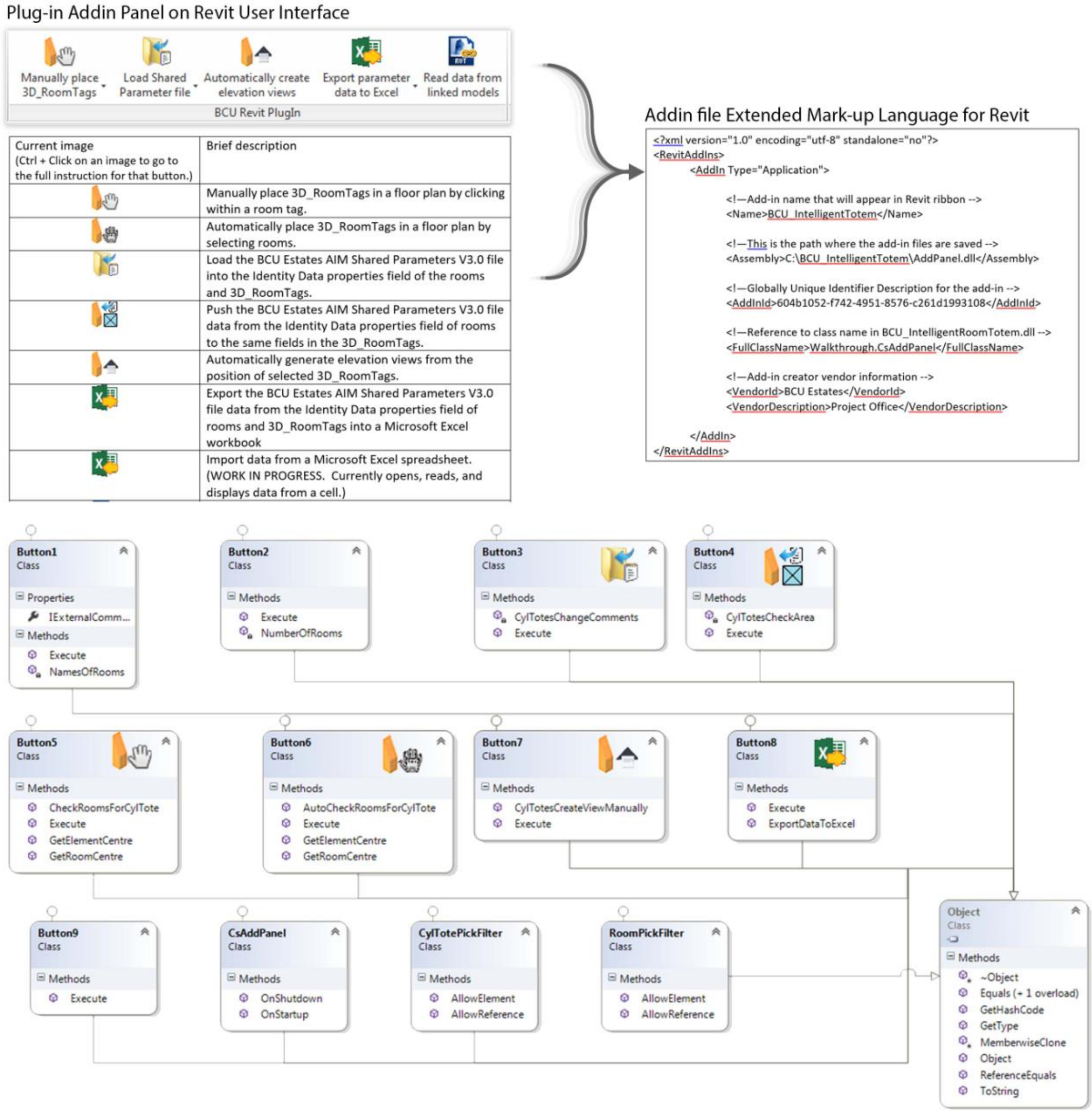


Figure 7 – Screen dump of front-end GUI