An OpenBIM workflow to support collaboration between Acoustic Engineers and Architects

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Abstract. Architects require the insight of acoustic engineers to understand how to improve and/or optimize the acoustic performance of their buildings. Normally this is supported by the architect providing digital models of the design to the acoustic engineer for analysis in the acoustician’s disciplinary software, for instance Odeon. This current workflow suffers from the following challenges: (1) architects typically require feedback on architectural disciplinary models that have too much geometric information unnecessarily complicating the acoustic analysis process; (2) the acoustician then has to waste time simplifying that geometry, (3) finally, this extra work wastes money which could otherwise be spent on faster design iterations supported by frequent feedback between architects and acousticians early in the design process. This paper focuses on the architect / acoustician workflow, however similar challenges can be found in other disciplines. OpenBIM workflows provide opportunities to increase the standardization of processes and interfaces between disciplines by reducing the reliance on the proprietary discipline specific file formats and tools. This paper lays the foundation for an OpenBIM workflow to enable the acoustic engineer to provide near real time feedback on the acoustic performance of the architectural design. The proposed workflow investigates the use of the international standard IFC as a design format rather than simply an exchange format. The workflow is presented here with the intention that this will be further explored and developed by other researchers, architects and acousticians.

1. Introduction
The design of spaces is a core service provided by architects. To make spatial design decisions, architects require guidance from a wide range of disciplines. Spaces, such as offices, schools, museums etc., require specific acoustic conditions to support the comfort of the occupants. As such, it is essential that acoustic parameters, such as reverberation time, speech transmission index, early decay time etc., are investigated sufficiently early in a design process, to ensure the desired design values of these factors are achieved before the design of the spaces and the materials are ‘locked’. Information that is relevant to the architect during the earlier design phases includes but is not limited to; recommended changes to the overall geometry to mitigate unwanted acoustic phenomena, such as flutter echoes, and the required areas of acoustically absorbing materials to be incorporated in the project. It is therefore important that architects collaborate with acoustic engineers in the early stages of the design to understand how to improve and or optimize the acoustic performance of their buildings. Building Information Modelling (BIM) has previously been offered as a solution to support issues of collaboration around digital asset
information in the AEC. However, studies that incorporate BIM to support collaboration can be limited by a focus on the tools that are used to solve the tasks. For instance, the primary tool for room acoustic design and analysis is acoustic simulation. A number of both proprietary and open-source room acoustic simulations tools exist, such as Odeon, CATT and EASE (proprietary) and Pachyderm (open-source) [1]. Most of these tools rely on geometric acoustic simulation methods, such as ray-tracing or the image source method [2]. Recently wave-based simulation methods have emerged as an alternative to geometrical acoustics methods, which offer more accurate simulations but are hampered by longer computation times [3], [4]. This non exhaustive list of tools shows that the investigation into supporting the collaboration between the architects and acoustic engineers could quickly be reduced to a question of which tools to use.

2. OpenBIM
An alternative approach is provided by ‘OpenBIM’ tools and processes. BuildingSMART [5] presents 6 principles of openBIM: (1) Interoperability is key to the digital transformation in the built asset industry. (2) Open and neutral standards should be developed to facilitate interoperability. (3) Reliable data exchanges depend on independent quality benchmarks. (4) Collaboration workflows are enhanced by open and agile data formats. (5) Flexibility of choice of technology creates more value to all stakeholders. (6) Sustainability is safeguarded by long-term interoperable data standards. The OpenBIM principles are supported by 6 core standards and guidelines promoted by BuildingSMART to support OpenBIM, including: Industry Foundation Classes (IFC); Information Delivery Manuals (IDM); Model View Definitions (MVD); BIM Collaboration Format (BCF); BuildingSMART Data Dictionary (bSDD); and finally, Information Delivery Specification (IdS). IFC was first released in 1997 [6]. It is the prevalent open standard to exchange building models. It is defined by BuildingSMART as a “standardized, digital description of the built environment, including buildings and civil infrastructure. It is an open, international standard (ISO 16739-1:2018)”. The IFC schema specification is the primary technical deliverable of buildingSMART International to full its goal to promote openBIM”.

In addition to IFC, BuildingSMART also support the development of IDM to support stakeholders to know when and which different kinds of information have to be communicated. The ISO 29481-1:2010 “Building Information Modelling - Information Delivery Manual - Part 1: Methodology and Format” standard has been developed by buildingSMART to have a methodology to capture and specify processes and information flow during the lifecycle of a facility. MVD addresses the challenge that federated IFC models can be quite large (as complete descriptions of the building). MVD therefore is a methodology to frame a subset of the building that is relevant for the use case / collaboration in question. In this sense the MVD, IDM and IFC are tightly coupled concepts. Creating a single object model for the construction industry in the form of IFC is already a significant challenge. This challenge is magnified when trying to predict what classes and relationships stakeholders in specific collaborations would require in ‘their own’ subset of the IFC format. There are currently a limited number of MVDs available and none for the acoustic architectural collaboration. The BCF format aims to directly support collaboration by capturing the context and relevant information for a stakeholder when submitting a BIM issue. It is possible that this format could also be used to return analysis results, however integration of this is beyond the scope of this paper. The bSDD provides an opportunity to lookup specific classes for terms such as how reverberation time could be recorded in an IFC for instance, cross referenced against the language and local guidelines and classification systems. Finally, IdS is a BuildingSMART specification that defines how objects, classifications, properties, and even values and units need to be delivered and exchanged.

3. (Open)BIM Ecosystem
As can be seen from the range of standards and guidelines offered by BuildingSMART, BIM is more complex than just selecting the right digital tools and exchange formats. Gu et. al. [7], describe BIM as an ecosystem. They emphasize three aspects of people, processes and products and their coevolution based on similar perspectives from the innovation literature. From an OpenBIM perspective we can then
look at the different aspects of an (Open)BIM ecosystem in acoustic architectural collaboration. For instance, from a people perspective, Videbæk [8] found that “room acoustics is prioritized very low in the design phase and that especially the architects are in need of tools to handle acoustic related challenges”. The architects’ lack of perception of room acoustics cannot be solved by any single BIM tool but requires a thorough look at the design process and the values of its stakeholders. At the same time, an overarching issue from the process and tools perspective is the challenge of vendor lock in, where in the user develops part of the solution in a tool which has not been designed to make it easy for the data to be translated to a different software.

From a tools and processes perspective, recent additions to this OpenBIM ecosystem include methods and tools for schedule and cost management in infrastructure projects [9]; to studies on as built data [10] and acoustics [11]. However, these studies tend to focus on the use of a static IFC file to exchange information between software. An alternative approach, promoted by Moult, [12] extends the basic OpenBIM principles to use IFC as the design model format (object model) rather than just the information exchange format. Emerging OpenBIM tools, such as BlenderBIM based on IfcOpenShell, use IFC as an internal data model.

Finally, what is meant in this case by the ‘product’ of the OpenBIM ecosystem? We could argue that it was the building or its components. An alternative conception is that the product is the professional service of guidance that the stakeholders offer each other in their collaboration towards the project goal of the design of the building. McGinley & Krijnen [13] have explored how IFC can be used for the analysis and feedback on the design model to support this perspective on the OpenBIM ecosystem, however they do not explore the implications for a specific collaboration. Therefore, this paper asks the question of how an OpenBIM ecosystem perspective can support collaboration between architects and acousticians?

4. Methodology
To illustrate this point, a ‘typical’ acoustician architectural collaboration is described in the following section including the BIM ecosystem ‘product(s)’. The potential of OpenBIM to support the acoustic-architectural collaboration is discussed in relation to each task with the suggestion to add or remove specific some tasks. Based on this, an alternative workflow is presented. This new process is meant as a sketch to provide a foundation for future work into using OpenBIM approaches to support collaboration in the AEC.

5. Analysis of current Acoustician Architect collaboration
There is not a single product of the collaboration of between acousticians and architects. Each task or process in the collaboration has a product.
It is therefore important to be able to ‘look into’ each task in the collaboration. The OpenBIM IDM (Information Delivery Manual) uses Business Process Modelling Notation (BPMN) [14]. BPMN is a common method to model business processes and can be used to model the OpenBIM ecosystem (people, process and products) between stakeholders in a collaboration. It describes the tasks that each stakeholder performs in a collaborative process and how the output of a task triggers another task. Berard and Karlshøj [15] in a review of IDM, suggest the use of PRR (Production Rule Representation) from the Object Management Group (OMG) as an alternative to make the modelled rules and tasks more explicit. This could be explored in future work together with the Rule Interchange Format (RIF) from the W3C which focusses on a translatable representation of rules that can integrate with existing rule formats. However, for simplicity and consistency BPMN is used here in the modelling (Figure 1) and the tasks are interpreted as subject - verb - object, which results in a product.

The current architect to acoustician collaboration can be seen in Figure 1 and is modeled in a BPMN diagram with 7 task nodes, 1 gateway and 2 information exchanges. The model consists of two parallel swim lanes which contain the activities (tasks) of the architect and acoustician, respectively. A strength of this representation is that it shows the overlapping and dependent processes between the architect and acoustician. Figure 1 shows that the current workflow for the performance of an acoustic analysis on a given project entails the architect providing digital models of the design to the acoustic engineer for analysis in the acoustician’s disciplinary software, for instance Odeon. Odeon is an acoustic analysis tool used by acousticians worldwide. Figure 1 helps: to identify where the problem occurs; to whom; and to plan the implications of any proposed changes to the workflow. The tasks of the current process are presented below in subject - verb - object form and used to summarise the challenges from an (Open)BIM ecosystem perspective.

**AR1: Architect Produces model:**

In this task the product is the model. This product should provide the information needed by the acoustician to support their analysis. These are the kind of issues that are addressed in an Information Delivery Manual (IDM), however the architectural model that is exchanged typically contains the information that is of interest to the architect, not the acoustician. Therefore, this could be a good use case for MVDs, however to see if this is possible, we need to look at the requirements of the acoustician for the information exchange:

1. Openings should be open. They should be surfaces with absorption coefficient set to 100%.
2. The relevant space may not necessarily be defined as a fully enclosed space. For the use in acoustic analysis the model has to be “water tight”, with no significant leaks or holes in the model.
3. The surfaces must be planar and not warped, so curved surfaces are subdivided into small planar surfaces.
4. The materials present in the model should be clearly classified in a way that is logical to the acoustician and their tools.
5. Odeon as an example recommends a simplification process using the rule of thumb that any detail with dimensions less than approximately 34 cm (the wavelength at 1000 Hz) may be omitted. This may be difficult to enforce with an MVD but the exclusion of detail that is superfluous to the analysis such as the geometry of the door handles could be managed by an MVD. However, this might not be the correct technology to consider simplifying or ‘translating’ the data.
6. Try and split up independent spaces so that they can be treated as separate problems.
7. Architectural BIM models contain semantic information about the elements in the building including their dimensions materials relationship to each other that could make it easier for the acoustician to know which elements should be considered in which rooms.
8. The acoustician may ask the architect to exchange their information in IFC.
OpenBIM Ecosystem Consideration: It is therefore important that the ideal process includes an analysis of the information exchange requirements as would be supported by IDM. Additionally, we should consider the needs of the architect as the party that is receiving the product from the acoustical engineer. The acoustical engineer is mostly interested in the air domain inside of a space and the immediate boundaries of this, so the engineers should be able to select a space within the model and all irrelevant geometrical features outside of the domain should be automatically hidden. Striking the right level of simplification of geometrical details in a model for acoustic analysis is a major part of the analysis process and therefore the acoustic engineer should be left with a set of effective tools in the BIM model, rather than a completely automated process. The materials that the building designer has applied to the model should be carried through to the acoustic designer, where it should be possible to split surfaces for more specific material application.

AC1: Acoustician remodels the data
Based on the issues above, the acoustician is often required to remodel the relevant space before commencing with the actual analyses, meaning that: (1) The initial modelling effort of the architect is wasted due to a loss of geometric data (a simpler model could be exchanged earlier in the process if it were available) (Figure 1: AR1). (2) This commonly results in rework on the part of the acoustician to extract the parts of the model which are of interest to them. This rework is wasteful and increases the time and cost for feedback from the acoustician to the architect which ultimately affects the probability of the advice being utilised and properly implemented in the project. (3) The semantic information (if it is a BIM model) is most probably lost in the remodelling by the acoustician (Figure 1: AC1).

This paper focuses on a ‘typical’ workflow of setting up the acoustic simulation model in a software such as Odeon. To achieve this, it is required to export/convert the model from the architect, to a suitable format, such as dwg, dxf or sketchup, depending on the analysis tool. Odeon, for instance, has two input formats, DXF and 3ds, which are both primarily geometric formats and a live link established to SketchUp. There is mention of the IFC format but this is as a route to SketchUp from where the data is stripped of the semantic information in the IFC format and only the simplified geometry is retained. Commonly this is done by mapping the class names in IFC, i.e., IfcDoor to a door layer in Odeon. The power of IFC is that it models not just the elements of the building but the relationships of all the objects in the building, for instance from an acoustician perspective it is useful because IFC models all the elements that bound or are contained by a specific space (IfcRelContainedInSpatialStructure).

However, the current workflow exchanges only the geometry which can be of a high level of detail even if the level of design (certainty) in the model is low. As such, every detail, no matter how small, is carried through to the acoustic analysis model resulting in impractical computation times. Furthermore, should the IFC model contain any leaks or holes which are of importance to the analysis, the location of these may be exceptionally difficult to detect. Additionally, the loss of the semantic information and the elements relationships when converting the element from IFC file to geometry in a layer does not identify different materials within that layer. For example, all doors may simply be identified by the layer “doors”, and treated equally as such, regardless of the fact that their predominant material may differ between wood, glass or metal. In the IFC these elements would have their own IfcMaterialSets and IfcMaterials with their own IfcPropertySets.

Alternatively, the acoustician has the option of importing a DXF or 3ds version of the design model directly into Odeon. However, this option contains the same challenges as listed above. In practice, it is far more common for the acoustician to fully remodel the relevant space using the modelling software SketchUp. During this process, building parts, such as windows and doors, are simplified and often simply represented by a single surface. Other elements of the design model may be omitted completely if the acoustician estimates their influence on the acoustics to be negligible.

AC2: Acoustician performs the analysis:
Due to the simplification process in the previous task, when the simplified model is imported into Odeon, the material parameter “scattering coefficient” is then adjusted to compensate for the sound diffusing
effect of the omitted details. Once the acoustic designer has the geometry ready for analysis it is a matter of applying material properties, inserting sound-sources and receivers, and running the analysis. The acoustic designer often runs a number of alternative material choices, exploring how the space responds to acoustic treatment and gives recommendations from there. The recommendations in the early stages can be recommendations of material groups, perhaps along with a traffic light grading. However, in many cases it is about identifying problems in the design and assessing risks related to the acoustics of a given space. Figure 2 shows a typical comparative analysis conducted in Odeon to provide the feedback (product) on the acoustic quality of the space with and without an acoustic ceiling.

Figure 2. Shows a comparison of two options calculated in Odeon.

**AC3: Acoustician produces the report**

The acoustician then writes a report based on the values they derived from the analysis in Odeon. For instance, in option b from Figure 2, the acoustician provides the following values in Table 1. This product (the report) is unfortunately 2 steps removed from the information in the original architectural model.

| Reverb Time | 125 | 250 | 500 | 1000 | 2000 | 4000 |
|-------------|-----|-----|-----|------|------|------|
| T_{before}  | 1.42| 1.41| 1.39| 1.37 | 1.37 | 1.13 |
| T_{after}   | 0.59| 0.85| 0.57| 0.57 | 0.56 | 0.52 |

**OpenBIM Workflow Opportunity:** The feedback to the architect should be relayed directly in the building model. An overlayed layer on the model could include key acoustical parameters and a traffic light grading of the risk related to the acoustics of a highlighted space. Additionally, if the acoustic designer made new proposals to the geometry or materials these should be displayed on the overlay, with the before and after properties. In this way the communication between the two designers could take place directly in the modelling environment, leaving little room for misunderstandings and mistakes. Secondly the information is fed back into the IFC file. This could be achieved by writing back into an appropriate multi value property in an IfcPropertySet.

**AR2: Architect Reviews report**

At this critical point in the workflow, the product of the process is reviewed by the architect, the architect will then make the following decisions, (1) whether to update the model with the input from the acoustician, (2) to adapt their spatial design to the values in the report (unlikely) (3) to simply add more material in the form of acoustic panels to rectify the lack of integration in the design (likely). (4) if they explore changes; will they send these through to the acoustician to check? (Figure 1: Gateway 0) If not
the extra analysis could be a wasted business opportunity for the collaboration that could have added value reduced risk and increased the quality of the design.

**AR3: Architect Updates the model**
The acoustician’s model is decoupled from the architect’s model and if the acoustician suggested changes, these will not appear in the architect’s model and it will have to be remodeled, so that (the architectural design model) can be tested again by the acoustician. A solution for this could involve conflict or versioning handling tools, similar to those used in collaborative software development. An important aspect is that the acoustic designer is made aware of which simplifications are made and how it differs from the intended design.

**G0: Architect requests feedback [Gateway]**
Should the need for following iterations occur, the acoustician is then required to update their analysis model correspondingly before recalculating. repeating steps (AC1, AC2 and AC3). In summary, in the current process the value of the product offered by the acoustician is limited outside of the issues of the quality of the analysis because (1) the architect must waste time adding geometric and building information which is not required and complicates the acoustic analysis process; (2) the acoustician then has to waste time simplifying that geometry. The remodelling process increases the amount of time between model exchange and feedback. By the time their guidance is offered to the architect, many potential opportunities and alternative design and material strategies that could improve acoustic performance are lost. This lack of coordination, adds an additional cost to the product offered by the acoustician (Figure 1: AC3) which may reduce the chance of resending the model for feedback another time (Figure 1: G0) and creating more value in the project.

**OpenBIM Workflow for Acoustic Architectural collaboration**
Based on the discussion above of the current workflow and the identification of three opportunities for OpenBIM to support the collaboration between acousticians and architects. These additions to the process are shown in Figure 3 and summarised here.

- Requirements Analysis (Figure 3: P0 and Figure 3: P1) (supported by IDM), which capture the needs of the architects and acousticians before modelling or analysis starts.
- Addition of a ‘System’ swimlane, support automation of requirements and model checking in the workflow.
- Removal of the remodelling stage (Figure 1: AC1), this is replaced by the proposed system translates the model (Figure 3: S2).
6. Conclusion
This paper investigated the potential for OpenBIM approaches to support the collaboration between Acoustic Engineers and Architects. It described the idea of an OpenBIM ecosystem and used this to explore the potential existing OpenBIM standards, guidelines, schemas and specifications to support this collaboration. Current tasks in the typical workflow were identified. (Figure 1) Each task was investigated from an innovation based OpenBIM ecosystem perspective. This resulted in the sketch of an ‘OpenBIM workflow’ (Figure 3) to provide the foundations for future work to support the collaboration between acousticians and architects. This is relevant to the audience of IBPC because it provides a checklist and enables them to create their own roadmap for integrating OpenBIM tools into their workflow. From this point the potential advantages of this approach include (1) avoiding wasteful rework, (2) considering the needs of the stakeholders, (3) a focus on the product of each task, (4) mapping the process in BPMN could be extended to machine executable rules, to further support automation of the processes discussed in this paper, (5) reduction in the loss of semantic data by using open and standard formats (in this case IFC) to make sure that information about the properties and relationships between elements is retained throughout the information exchange, (6) integrating existing tools such as Odeon into the workflow, whilst still being open to emerging OpenBIM tools such as BlenderBIM and custom tools developed in IfcOpenShell for instance. In future work new tools to test the workflow will be developed.

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