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Executive Summary of the Thesis

Hallbridger: Real-Time Acoustic Control in Multipurpose Halls

Master of Science in Music and Acoustic Engineering

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1. Background and Motivation

Modern cultural venues are under pressure to deliver diverse programming—from conferences and spoken-word events to orchestral concerts and opera—within a single physical space while meeting expectations for sustainability, efficient land use, and cost control. Achieving this versatility hinges on variable acoustics and agile facility management (FM): the same room must alternate between highly absorptive configurations that favor speech intelligibility and more reflective layouts that enhance musical richness. Historically, such adaptability was considered impractical in room acoustics due to technological and operational constraints; recent advances in materials, control systems, and architectural techniques have fundamentally changed that assessment. Concurrently, Building Information Modeling (BIM), Digital Twins (DT), and the Internet of Things (IoT) provide a pathway to integrate the physical hall with its digital counterpart, enabling data-driven configuration, remote visualization, and predictive evaluation of acoustic performance. Yet, in practice, the lack of standardized, dynamic data bridges between on-site FM systems and digital models has hindered adoption—especially in venues with numerous moving elements and complex acoustic behaviors. This integration gap is the central motivation for the thesis. The core problem addressed is the absence of a robust, bidirectional, and generalizable interface that connects a theater's facility management/control software with a 3D digital model to keep geometry and configuration synchronized in real time, and to expose acoustic information that is meaningful to operators during setup and rehearsal. Today, theaters often rely on manual procedures, ad-hoc spreadsheets, or non-interactive models; these approaches are brittle and slow, preventing operators from testing configurations virtually and reducing turn-around time between events. There is no widely adopted protocol that dynamically couples on-site moving elements (e.g., variable acoustic panels, curtains, stage machinery) with a simulation-ready digital representation, which blocks the road to an integrated BIM/DT-driven workflow in room acoustics [2][1].

2. Objectives of the work

This thesis sets out to design and implement an ad-hoc software interface, named Hallbridger, that

1. ingests real-time hall configuration data from a venue's FM system;

2. updates a 3D model of the hall using those real hall data;
3. highlights acoustic information (global reverberation time, RT) to illustrate the acoustics of the current 3D hall's configuration

Even if the first software release focuses on the Roberto de Silva theater in Rho, Milan, its installed stage-control software (CURIO© by Decima 1948) and a BIM-compatible IFC model of its hall, the long-term goal is to lay the foundation for a future BIM/DT system that could incorporate IoT sensors, VR visualization, and on-the-fly acoustic simulations, while remaining extensible beyond a single theater or FM platform.

3. Context: the Roberto de Silva theater

The Roberto de Silva theater is a 2022 multipurpose venue designed for flexible programming. The main hall integrates fixed acoustic treatments (e.g., perforated wood over absorbers on the rear wall; convex overhead panels to distribute early reflections) with extensive movable elements, most notably a number of pivoting panels on the lateral walls organized into sectors and actuator-controlled vertical array groups. Opening a panel reveals absorbing material; closing it increases reflectivity. This architecture underpins three primary configurations: concert hall, opera/ballet theater and congress hall, each defined by coordinated positions of panels, curtains, sliding doors, and the orchestra pit. To quantify the venue's acoustic variability, measurements adhering to ISO 3382-1 captured global RT (T_{30}) across octave bands from 125 up to 4000 Hz under selected panel opening layouts (e.g., CLOSED, OPEN, sector-based combinations)[3]. These values are included in Hallbridger as the starting point for acoustic evaluations.

4. Conceptual framework: BIM, Digital Twins and IoT

Within a comprehensive framework, BIM (or, in this case, BAM - Building Acoustics Modeling) coordinates geometric and non-geometric data across the facility life cycle; a Digital Twin keeps the digital model synchronized with the evolving physical state; virtual reality permits a tridimensional simulation experience; IoT delivers real-time environmental and occupancy data (temperature, humidity, seat occupancy, background noise) that influence room acoustics. Integrating these streams enables remote monitoring and moving element control, virtual testing of configurations' acoustics, and automation for standard setups. The thesis positions Hallbridger as a first "bridge" block between the physical hall (actuated equipment managed by the FM system) and its digital representation (IFC-based model), opening the way to future full BAM/DT workflows.

5. Proposed solution: the Hallbridger interface

Hallbridger is a Windows application, accompanied by a custom Web API, that establishes bidirectional data exchange between CURIO© (the installed FM/stage control system) and an IFC model of the theater. Its design choices reflect pragmatic constraints at the theater and forward compatibility with BIM/DT:

- Input from the real hall: a UTF-8 text snapshot describing the status of moving elements, using a stable identifier scheme (e.g., left/right panel groups, stage equipment). Hallbridger ingests this file via the API, parses values, and updates internal dictionaries.
- Input from the digital hall: an IFC model constructed in Revit and exported for open manipulation; for this first version, the model includes a subset of pivoting panel arrays (sector 0C), enabling edits outside Revit via xbim tooling.
- Bidirectional flow:
    - Real → Digital: overwrite IFC parameters with the latest real hall values and refresh the 3D view;
    - Digital → Real: export a CURIO-readable snapshot of the current IFC state to support future "confirm configuration" workflows and actually make the real hall elements be deployed (import on CURIO's side to be implemented by its vendor).
- Operator experience: side-by-side data grids (real vs. 3D) with discrepancy high-

- lighting, an interactive 3D viewer, and an acoustic table that lists global RT values for known configurations and highlights the one detected in the current 3D layout.

While not a complete BIM/DT solution, Hallbridger materializes the critical missing interface, demonstrating real-time consistency between the hall's actuated elements and its digital geometry and providing acoustic cues to operators.

6. Methodological approach

6.1. Software architecture and technologies

The system comprises a .NET WinForms client (GUI) and an ASP.NET Web API (modular parsers/formatters), designed for local deployment on the theater's isolated PC (Windows 10 Enterprise 2019). The xbim toolkit handles IFC I/O and geometry; IIS Express hosts the API locally; Swagger documents endpoints for maintainability.

6.2. Data models and identifiers

CURIO© exports integer strokes/positions per actuator (bounded values; panels: 0 = closed; equipment: distance from top), associated to element codes (e.g., PS/PD for left/right panels + numeric ID). In the IFC model, corresponding elements expose angle/position properties (e.g., PANEL ANGLE in a shared parameter within nested Revit families), which Hallbridger edits to mirror the real hall. Mapping is hard-coded in v1.0 (a known trade-off), paving the way to a configurable mapping layer in future versions.

6.3. User interaction and use cases

Hallbridger provides manual and timed automatic flows to

- load real-hall data;
- load 3D hall data;
- update the 3D model from the real hall;
- export 3D hall data in a CURIO-compatible format.

Auxiliary functions include automatic discrepancy highlighting, 3D element property editing, camera repositioning, and a high-performance rendering mode for lower-spec hardware.

6.4. Acoustic dataset integration

The acoustic tab embeds the measured global RT table (T_{30}, octave bands) and identifies the current 3D layout among the recorded panel configurations, flagging the corresponding row so the operator can anticipate the average reverberation behavior for that setup. This is a lookup-based approximation that will later be replaced or augmented by calibrated simulations and occupancy-aware interpolation.

7. Results

7.1. Working bridge between CURIO© and IFC

Hallbridger v1.0 successfully reads a CURIO-generated snapshot, updates the IFC model, and visualizes both tabular data and the 3D scene, proving the feasibility of real→digital synchronization on an offline, secured PC. Conversely, it can export digital state back to a CURIO-readable file format, completing the conceptual loop (pending CURIO's import feature).

7.2. Scalable software design

The API's parser/formatter abstraction prepares the ground for multi-FM support (beyond CURIO©). The IFC/xbim choice avoids vendor lock-in and aligns with BIM practices. The UI already accommodates essential professional tasks: discrepancy visualization, editing, exporting, and data flow automation.

7.3. Validation under realistic constraints

Although live tests in the theater were unavailable (operational constraints), the exported 3D snapshot was validated by the vendor as readable by CURIO©, indicating format compatibility and readiness for in-situ trials.

8. Limitations and future developments

A non-exhaustive list of possible future work directions follows.

8.1. BIM system implementation and governance

The system should evolve toward a full BIM ecosystem by enriching the IFC with structured non-geometric data (materials' acoustic properties, maintenance schedules), adopting BEP/IDS/BCF processes, and deploying a Common Data Environment (CDE) for collaborative model management. Besides, a case-specific DT layer needs to be designed, with real-time data ingestion (temperature, humidity, occupancy, background noise) and bidirectional synchronization, optionally presented in VR for immersive inspection and auralization of configuration changes.

8.2. Acoustic evaluation method

The acoustic tab relies on pre-measured global RT for selected panel layouts, not on full simulations or occupancy-aware estimates; one of the next steps consists in extending the RT dataset with additional measurements and implementing calibrated simulation pipelines. Development of interpolation procedures for partial occupancy and hybrid setups (e.g., jazz big band with partial amplification) is advised, thus producing seat-region-specific RT/clarity metrics and listening trials in VR.

8.3. 3D model completeness and fidelity

The IFC currently includes a subset of pivoting panels (e.g., sector 0C) and does not yet represent all stagecraft equipment in detail. In a new software release, the model should incorporate all pivoting panels and stagecraft elements; also, panel-by-panel angle variance within an array (upper vs. lower maximum aperture) could be modeled.

8.4. Loop closure on the FM side

While Hallbridger can export a CURIO-readable file, CURIO© lacks an import function at present; true digital→physical actuation requires that capability to be added by the vendor.

8.5. Generalizing FM connectivity

Hard-coded mappings are present in Hallbridger 1.0, both for the associations between CURIO identifiers and IFC elements and for CURIO data interpretation. This is adequate for a pilot but must be replaced with exposed configuration UI for identifier mapping and user-configurable mapping to scale across venues and FM platforms. This would complete the API modularization to support multiple FM systems. Unit of measurements and database storage for acoustic and configuration histories compete the first, evident possible software improvements.

8.6. Operational deployment

Privacy and security issues compel all system components to lie on the same on-premises PC. It is suggested to define a secure test environment in the theater for end-to-end trials, including remote supervision options that respect the venue's network policies while enabling multi-venue oversight.

9. Conclusions

This thesis develops Hallbridger 1.0, a software interface between a theater's facility management system and a BIM-compatible 3D model and a first attempt to build the communication channel in between twins of a DT system, delivering bidirectional real-digital synchronization. Despite representing a compromise between a pure data-exchange application and a complete, BIM-compliant system, this first program version establishes a scalable foundation for further integration with IoT, VR, and acoustic simulations — a practical pathway to Building Acoustics 4.0.

References

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