

CONVIS: A tool enabling uninterrupted operation during refurbishments of complex buildings

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Abstract

Clash Detection refers to the identification of geometrical overlaps within a Building Information Model (BIM). This paper seeks to extend the notion of overlapping to activities: Given a construction site within a building, we seek to find clashes between construction activities and occupant routines. Such a situation is often encountered in the context of refurbishments of complex buildings operating 24/7 (e.g. airports, train stations, hospitals, prisons). By finding the influence radii of adverse effects resulting from construction - i.e. dust, noise and vibrations, functions may be temporarily relocated in order to guarantee uninterrupted operation. Our tool CONVIS implements these simulation and scheduling aspects and seeks to provide a digital project plan for refurbishments in the said context.

Keywords: Complex Buildings, Construction Site, Simulation.

Introduction

During the renovation of complex buildings construction activities need to be separated from daily operation due to dust, noise and vibrations. Considering the concrete example of a hospital (Zhang et al. 2013), we observe that

- vibrations can make electronic instruments for monitoring patients unusable
- loud construction activities can cover a heart alarm in the ICU; sudden noises can furthermore be dangerous during surgery operations
- dust dispersion is dangerous - especially for patients at high risk for invasive Aspergillois (D'Alessandro et al., 2007)

Separating daily operation from construction activities poses a scheduling and allocation problem which is hard to solve since no integrated planning tool exists. In our prototype implementation, we have thus implemented a common environment in which we are able to plan and visualise both aspects. Our tool CONVIS allows for Clash Detection between construction and work activities and takes the form of a digital project plan with a time-based view. As data basis, we use exported schemata coming from CAAD or BIM packages.

Background

Clash Detection has been dealt with mostly in the context BIM, either in a 3D (geometric) or 4D (geometric and time-based) view of a project (Azhar 2011). In that context, clashes have been characterized by their type (see Table 1) and classified according to possible resolution strategies (see Table 2). Both

of these notions of Clash Detection are linked to the geometric side only. However, this results in an oversimplification if one considers the context of renovation or refurbishments of a complex structure (e.g. a healthcare building) which remains in operation during the construction period. Inside such buildings, it would be favourable to also consider clashes between construction activities and work routines, which in turn are based on stakeholders and technical elements serving daily work routines. Rather than considering construction activities as such, this work deals with their effects split up into the three categories *noise*, *dust* and *vibrations*.

Table 1: Geometrical Interference classification

TYPE OF CLASH	DESCRIPTION
Hard	clashes between 2 or more elements.
Clearance	element A may/may not intersect element B, occurring at a lower distance than the tolerance (e.g. Due to overheating two elements must be placed at a determined safety distance).
Duplicate	two elements have the same geometry and are placed within range of tolerance. If the tolerance is zero, they occupy the same position.

Considering these three categories requires a certain regulatory framework which may take its concrete form in either national or international law. For example, the European regulation states that exposure to noise should not exceed 87dB. In cases where sound levels exceed 80 dB, sound

insulation measures are obligatory (Directive 2003/10/CE). In previous legislation (UNI EN ISO 11690-1:1996), it was established that an exposure to more than 80 dB may last only for a few minutes. Similar regulations also exist for the respiration of dust (e.g. CFR 29 1926.55) and the acceptable levels of vibrations (e.g. ISO 4866:2010).

Table 2: Colour classification of clash detection

TYPE OF CLASH	COLOUR	DESCRIPTION
New	red	interference identified for the first time through a new test.
Active	orange	interference identified in a previous test, not yet resolved.
Reviewed	blue	previously identified interference, manually tagged as detected.
Approved	green	previously identified interference, manually approved.
Resolved	yellow	previously identified interference now resolved.

The risk of noise exposure is real and for this reason the World Health Organization (WHO) recommends a maximum noise level e.g. for hospital environments in the range of 45 dB (but not exceeding 80 dB which is the said maximum; see Castro et al. 2013). However, some analysis highlight that the level of noise recorded exceed these recommended levels: In Austrian hospitals, for example, a level of 65 dB has been observed, while Spanish hospitals may have as much as 55 dB in practice (see again Castro et al. 2013).

The study of maximum acceptable noise levels has arguably as much to do with science as with subjective assessment of the context (Choiniere 2010); In Italy, current regulations thus state acceptable noise levels according to functions, from 30 dB (Hospital rooms) to 40 dB (General service areas) (see Table 3), in accordance with UNI 8199-1998 and UNI 8199-2016 (Uguccioni, G. 2005). Likewise, diversification trends are also in effect for dust and vibrations: The Canadian Centre for Infectious Disease Prevention and Control, for example, has proposed a proactive approach regarding the dust particle risk resulting from a classification system, which frames the construction site activities within the hospitals in 4 specific categories (from non-invasive activities to significant demolition and reconstruction [after Moscato et al. 2007]; see Table 4).

A tool supporting actual construction work must thus be fully customizable to individual standards, which is why we have made our implementation parameterisable with regards to acceptable levels for dust, noise and vibration.

Table 3: Noise limit for hospital environments

ENVIRONMENT	NOISE LIMIT
Hospital rooms	30 dB(A)
Wards	40 dB(A)
Operating theatres	35 dB(A)
Connection zones	40 dB(A)
Visitors area	40 dB(A)
General service areas	40 dB(A)

Our tool uses the paradigm of a digital project plan. It shows a time-dependent visualization of construction activities and their effects. Similar efforts have been previously made by Trento et al. (2014), who have linked construction entities and activities for hazard prediction. However, the authors are more geared towards representation of safety rules within BIM rather than simulation of effects (as in our case). On the other hand, they are performing their case study *within* a BIM environment to which our approach is simply a client (export of schemata from CAAD or BIM into our tool). Conceptually, our approach is part of the movement towards BIM lifecycle models: As operation and refurbishment are happening at the same time, it makes sense to think about a common data basis (see e.g. the U.S. Healthcare BIM Consortium - HBM - which supports the increase in data interoperability for the Facility Life Cycle Management, as reported by Linehan 2013).

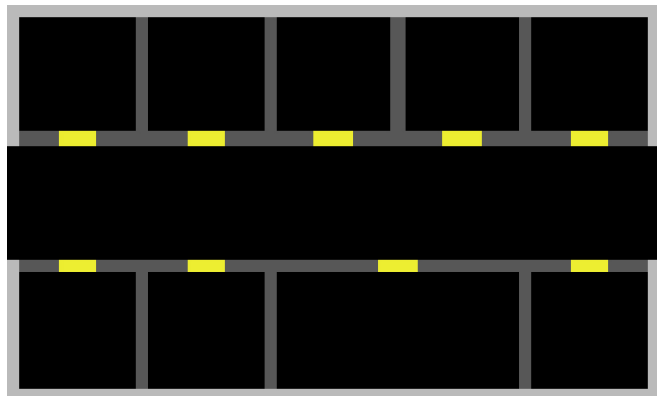


Figure 1: schema of ward and its characteristics (e.g. materials, sound insulation capacity)

Methodology

Our main aim is to reduce the negative impact of construction activities on the surrounding building environment. In order to be applicable even for early stages of design, we use schematics (room boundaries as opposed to full-fledged representation such as in IFC), on top of which we annotate planned activities (construction; regular work routines) in a

time-based manner. The influence between these two types of activities is furthermore simulated (particle-based noise, dust and vibration simulation) and brought to the attention of the tool user via visualization. Our workflow includes the following steps:

- **Export of a spatial model to schematics:** A BIM typically acts as a spatial database stating the location of walls and entrances plus their composition (material). We export the plans of rooms *as bitmaps* and process them within a graphics software (wall and door type/material encoded as colours; see Figure 1).

Table 4: Risk matrix of construction activities

TYPES OF CONSTRUCTION ACTIVITIES	EXAMPLES OF CONSTRUCTION ACTIVITIES	LEVEL OF RISK
<p>TYPE A Inspection and non-invasive activity, without generating dust and drilling walls</p>	<p>Removal of false ceiling panels for visual inspection; Painting; Re-paneling walls; Small electrical work; Small interventions on ventilation or terminal hydraulic Systems that require no more than 15 minutes.</p>	<p>LOW</p>
<p>TYPE B Small scale and duration activities, generating small amounts of dusts</p>	<p>Skylight well access; Drilling or cutting walls or false ceilings or paneling; Repairing cracks in the walls, scraping or shaving for painting; Installation of lines of electrical or telephone or internet cable in wall; Medium interventions on ventilation or hydraulic (final section) in multiple environments that require less than 30 minutes.</p>	<p>MEDIUM</p>
<p>TYPE C Interventions that generate from a moderate to a high amount of dusts and require demolition or removal of fixed structures.</p>	<p>Removing floor or wall coverings; Partial reconstruction of walls until scraping or shaving for plaster or painting; Installation of pipes of hydraulic ducts, of ventilation, of lines of electrical or telephone or internet cable in ceiling or false ceiling; Medium interventions on ventilation or hydraulic (final section) in multiple environments that require 30 minutes up to 1 hour.</p>	<p>MEDIUM-HIGH</p>
<p>TYPE D Noteworthy work on demolition, reconstruction and renovation.</p>	<p>Complete removal of floor or wall coverings or ceilings; Complete reconstruction of walls until scraping or shaving for plaster or painting; Complete installation of pipes of hydraulic ducts, of ventilation, of lines of electrical or telephone or internet cable; Interventions on ventilation or hydraulic system in multiple environments that take over 1 hour to be completed.</p>	<p>HIGH</p>

- **Analysis of construction activities:** Data on intended construction activities can be derived either from project plans or by analysis of the construction sequence with the help of the BIM. This is, however, a manual step which lays the foundations for the later annotation of the exported schematics. In that process, parameterization according to the type of work (drilling - associated with a certain level of noise, dust and acting as a vibration source) needs to be conducted.
- **Analysis of daily routines:** Work activities and their spatial occurrence need to be analyzed with the help of a formal process model (available e.g. in the case of hospitals), by observation (in-situ survey) or expert interviews. We use a simplified model where each localized work activity acts as a receiver for dust, noise and vibrations; tolerance levels regarding the specific type of work have to be parameterized and checked by the simulation.
- **Import of schematics:** The exported bitmaps are imported into our tool, one bitmap per floor. Technically, we are using NetLogo 3D (Blikstein et al. 2005) as a platform, which is a modelling environment featuring a 3D cellular automaton in which agents (particles) can be simulated. Walls and doors are mapped to cells which act as environment for the simulation (conducted by particles).
- **Annotation of activities:** The 3D cellular automaton is populated with construction site activities and activities of daily work: For each construction activity (e.g. *wall removal*), we leave a spatial pin which is furthermore attributed with time (*start; duration*) and type of effect (*noise; dust; vibration; strength*). These construction activities will later act as sources for the said effects. On the other hand, we localize work activities within the construction site, parameterized by their time (start; duration) and acceptable levels of noise, dust and vibration. All in all, the sum of annotations resembles a virtual project plan. A time slider allows one to see the succession of different activities (see Figure 2). The resulting action - namely the relocation of different work activities and the implementation of constraining measures (such as sound insulation) is currently not implemented in the tool. These two items are left for future work.

Simulation and Visualisation: The construction activities (sources of adverse effects) and work activities (receivers of these effects) are simulated as shown in Figure 3: For each effect, we instantiate a particle that represents a sound wave, dust particle or vibration wave. The cell environment acts as a guide and constraint for these particles (e.g. air flow field in the case of dust). The effects of these particles can be observed visually (particles crossing into rooms where work activities occur) but can also be recorded in the work activity markers, which serve as receptors.

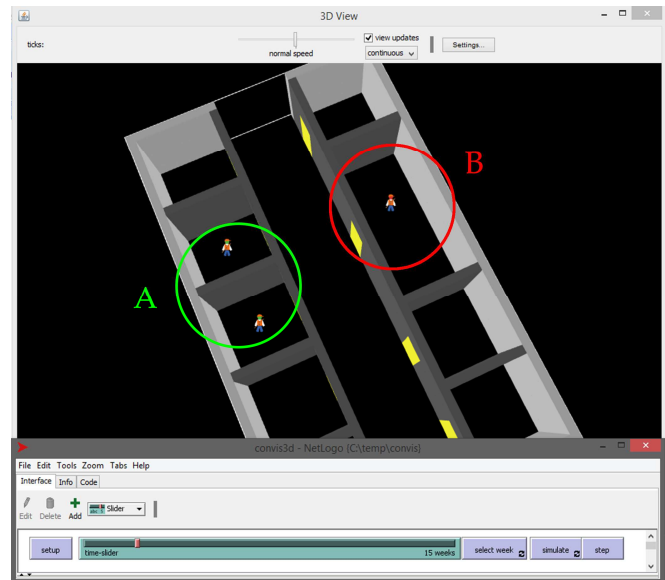


Figure 2: setting operation and construction activities (2 operation activities ^[A] and 1 construction site activity ^[B])

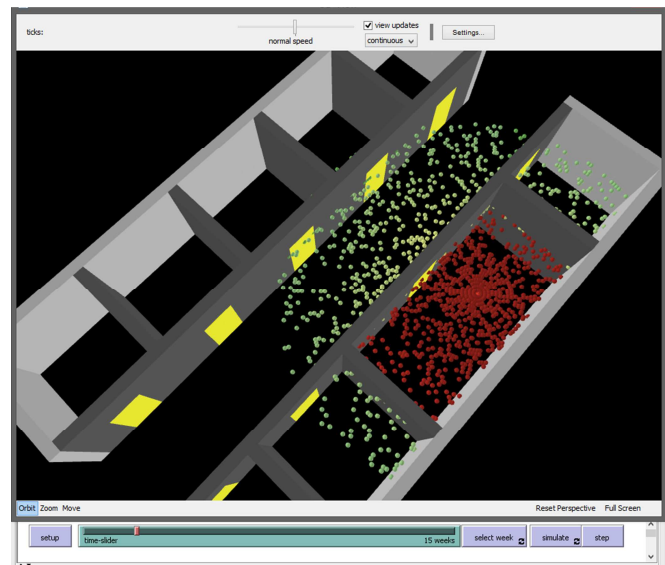


Figure 3: simulation of the noise impact of a construction site activity

Prototype

Our prototype was tested with a generic inpatient ward layout (individual rooms of 3x3m; larger rooms of double that size; see again Figure 3), where each cell within our model has 0.3m. Following that we tested with a similar ward of the Lower Austrian clinic Wiener Neustadt (826 beds) using the same cell resolution. The prototype in its current state allows

- to insert and edit different kinds of construction site and work activities, setting some parameters (e.g. *start time, duration*) as described in section 'Methodology';

- through simulation, one may monitor which area of the hospital is affected by construction site activities through time; one may also check which of the hospital activities are affected by which adverse effects

We are still implementing the ability to insert and set different kinds of construction site interventions (noise insulation etc.) and the ability to relocate work activities. These two features are left for future work, together with an in-depth description of the (cell-/particle-based) simulation models used.

Conclusions

We have worked on a tool that shows the effects of construction activities (noise, dust, vibrations) on daily operation (work activities) within complex building. The tool can be used for scheduling of construction activities such that an uninterrupted operation during refurbishment is possible. The intended audience is twofold: We support both operation management (e.g. business organisation, facility management) as well as construction professionals (scheduling of planned work items).

As future work, we seek to include the relocation of work activities and implementation of construction interventions (e.g. sound insulation). After this is done, we will move from our incubation environment (NetLogo 3D) into a Game Engine (Unity 3D) so as to improve the visual appearance and speed of our tool.

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