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The HOLISTEEC platform for building design optimization: an overview

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ABSTRACT: This paper proposes an overview of the design of the HOLISTEEC platform for optimized building design. HOLISTEEC is an EU-funded project, planned for a duration of four years and started in October 2013, which main objective is to design, develop, and demonstrate a BIM-based, on-the-cloud, collaborative building design software platform, featuring advanced design support for multi-criteria building optimization. The HOLISTEEC platform design proposes to implement a 3-layer approach, in order to enable for a better separation of concerns between low-level data modelling issues and, high-level functional and business issues. The design relies on a combination of proven data modelling standards and tools, in order to ensure the best effectiveness and to cover the widest spectrum of functions.

1 INTRODUCTION

Buildings currently use 40% of world energy, emit 40% of world carbon footprint, and use 1/5th of world available water. According to the Energy Performance of Building Directive, Member States shall ensure that by 2020, all new buildings are nearly zero-energy buildings (after 2018 for new buildings occupied and owned by public authorities), while less than 1% of existing space is nearly zero energy at present. These commitments can be met only if a significant shift occurs in the design and construction processes. Indeed, the schedule set by the EC and the member states is so tight that the usual innovation cycle (based upon prototypes and pilot operations) is not relevant anymore and the following evolutions are necessary: (i) Strong shift towards digital prototyping in order to ensure rapid integration of new products and processes on the market. (ii) Global assessment of design choices: Good products are necessary but do not guarantee the final high quality result – it is how they are combined and their impact as a whole which matter; (iii) integration of design and assessment activities, instead of individual optimization of multi domain requirements which often leads to conflicting solutions (e.g. acoustic-focused vs. thermal-focused design).

The HOLISTEEC project (Grant Agreement n° 609138), funded under the FP7 program (Energy-Efficient Building Public-Private Partnership) is intended to be a major contribution to the challenges described above. HOLISTEEC is a 4 years long, 9,7 M€ budget, 19 partners European project, which main objective is to design, develop, and demonstrate a BIM-based, on-the-cloud, collaborative building design software platform, featuring advanced design support for multi-criteria building optimization (HOLISTEEC 2013). In a few words, the HOLISTEEC concept mainly relies on the following assets:

- A combination of expert knowledge, brought by some major players of the European AEC sector, in building life cycle workflows and practices, business models, and value chain. This knowledge will be used as a base both for HOLISTEEC platform specification and for validation of the definition of the platform services;
- A loop-based methodological approach, enabling to take the right decisions at the right moment and minimizing their impact.
- A full-fledged BIM framework, encompassing all building-level physical and non-physical aspects in an integrated way, while also addressing neighborhood level description. This data model will heavily rely on and extend existing standards (IFC, CityGML) and will feature easy plug-in interfaces for

third party tools, e.g. CAD tools from the project partner Nemetschek;

- A holistic multi-physical simulation engine, able to capture and assess in an integrated way building performances in various dimensions at building and neighborhood level: energy, environment, acoustics, lighting;
- A web-based, BIM-enabled, on-the-cloud, collaborative design software platform. This platform will rely on the HOLISTEEC BIM framework, to provide collaborative design support services, encompassing building models exchange / access management and smart visualization;
- A building design decision support tool, relying on advanced artificial intelligence techniques and on the multi-physical simulation engines, able to provide semi-automated, focused, assistance for fast and optimized design decisions.
- Four real-world pilot projects on which the project partners will apply the HOLISTEEC solution both for new building and retrofitting design, and assess its added value and impact.

It is particularly expected that HOLISTEEC will make significant contributions in the fields of buildability and multi-scale, multi-physical building simulation, where some limitations remain (Scherer & Schapke 2011, Steel et al 2012, Welle et al 2011, Windisch et al 2011).

The aim of the paper is give an overview of the HOLISTEEC platform, and of its main components, with a specific focus on interoperability issues. To this end, the paper first provides a short review of the requirements dwelling from the definition of the HOLISTEEC method. Then, the architecture of the HOLISTEEC is outlined. One section is then dedicated to each layer of the platform (BIM infrastructure, BIM lifecycle information framework, and Multi-criteria design optimization tool), before concluding.

2 METHODOLOGICAL POINT OF VIEW – REQUIREMENTS FOR INTEROPERABILITY

In the framework of architecture, engineering and construction (AEC) industry, various data and information are taken into account and elaborated in each of the phases of the building project life-cycle (i.e., design, construction and maintenance). The same way, each project phase engages several stakeholders and organizations and therefore different computer applications and systems (Pniewski 2011). To properly support the use of this information, the involved actors need to be able to represent project data in a common and standardized form, which

provides a useful exchange of data among different computer platforms (Pniewski 2011). In this scope, the interoperability issues relate to the existence of complex information models, numerous (and increasing number of) vocabularies and software applications, and management practices in AEC industry.

The need of identifying proper set of principles and rules, able to classify the information requirements into specifications for data exchange, solving the interoperability issues, has been confirmed by the results of an investigation carried out within HOLISTEEC consortium (as part of WP1 about the definition of the methodology), among the partners directly involved in the building design and construction process. For the aforementioned purpose, a specific template has been developed and distributed in the form of a questionnaire in order to gather information on partners practice and direct experience in the different phases of the building design and construction process. One of the focuses of this research has been the investigation on critical issues/lacks experienced/identified in each project phase, carried out by means of including a lacks-description dedicated section of the questionnaire. The conclusions of the presented analysis have helped in the definition of a new and optimized building design methodology and have been relevant in the definition of the ICT-related requirements for HOLISTEEC design software platform and tools implementation.

In particular, three main categories of criticalities/lacks that have an impact on different design project phases have been identified: *data-related lacks*, *tools-related lacks*, *process-related lacks*. In the framework of this paper, the *tools-related lacks* category is the relevant one. This category has an impact both on the preliminary design and detailed design phases and is related to the underlined need of multicriteria-tools able to help in assessing the impact of design decisions on different project phases and with regards to different stakeholders' activities. In particular, the following needs have been highlighted:

- Need of design multi-criteria business tools at different level of detail has been highlighted. In the early design phases tools based on benchmarks shall be implemented while for the more detailed design phases multi-criteria tools based on simulations results shall be developed. In both cases the performance and technical aspects shall be assessed in close connection to the economical aspects.

- Need of tools interoperability in order to enable improvements in coordinating and planning design activities so that to minimize clashes between architecture, structure and services design. In the framework of building design, the lack of standardization and interoperability causes incompatibility between different models preventing members of the project team from sharing information rapidly and accurately and resulting in continuous and repeated data input activities, information redundancy, risk of inefficiencies and additional costs

3 HOLISTEEC PLATFORM ARCHITECTURE OVERVIEW

The HOLISTEEC work-packages related to the design and development of the software components of the HOLISTEEC platform are still in their first phases. However, some early choices have already been made, especially taking into account the outcomes of the business requirements elicitation as part of the methodological work-packages. The rationale for the architecture design is to rely on a layered approach, from the “raw” BIM implementation to functional services, dedicated to the end users.

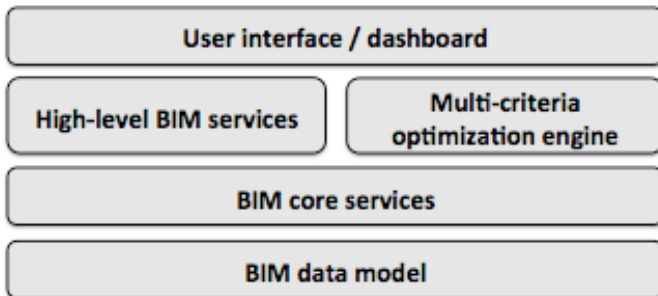


Figure 1: The HOLISTEEC platform architecture

The first layer (see section 4) includes the implementation of the BIM per se – it is basically a data model that complies with applicable standards, IFC and CityGML at first, and also provides a set of core services that facilitate data querying and management. As outlined in the next section, this layer (called *BIM infrastructure*) covers both building and neighbourhood levels data modeling. The second layer builds on this infrastructure, to bring additional services for dynamic management of building data during the entire life-cycle, providing high-level services to enable a collaborative and cloud-based building design process (section 5). A large part of the research work focuses on the design of an highly innovative multi-criteria optimization tool, that will enable for reliable evaluation of the design choices

along the most relevant and critical dimensions (section 6).

4 BIM INFRASTRUCTURE

The first essential goal of the BIM infrastructure is to provide a common neighbourhood-aware BIM data model repository that will serve for the different stages of the project life-cycle. Its second essential goal is to provide universal means of accessing the information models regardless of the specific business services used and the implementation mechanisms chosen. Making this infrastructure Service-Oriented Architecture (SOA) compliant will support achieving those goals.

4.1 Neighbourhood-aware BIM Data Model

HOLISTEEC sets the requirement of an integrated data model comprising all information needed at building and district level for various physical simulations (energy, acoustic, light, environment) and business services. In view of that the integrated model will follow a centralized approach based on the leading standards, IFC for the Building Information Model (BIM) and CityGML for the Neighbourhood Information Model (NIM). The main purpose of the integrated model will be to interlink BIM and NIM data using explicit links between building objects and district objects while keeping the whole integrity of both models. With this Multi-Modeling approach (Scherer & Schapke 2011) it is also possible to integrate in the integrated model other type of information from other data standards, such as geographical data, weather data, costs, documents, etc. Moreover this approach will enable the use of existing free or commercial tools supporting the implemented data standards, such as for example the Open IFC Tools (<http://www.ifctoolsproject.org>, etc.) or Allplan from Nemetschek.

For the implementation of the integrated BIM-NIM model and for information access a model server will be set up. This server will be built upon existing technologies like for example the BIM server from Nemetschek, Bim+. The management of the BIM-NIM integrated model will imply the definition of metadata like author, version, creation date, access rights, approval, level of detail, etc. They will be embedded in the data resources in order to manage access rights and to guarantee the traceability of the information in a context of collaborative work over the full life-cycle of a project.

4.2 Core Services

The goal of the core services is to search, retrieve and filter data from the underlying integrated information model. These will constitute a neutral layer

of predefined base functions providing domain and application independent resources for use on a higher level by the BIM or data management services. In view of that the neutral layer of core services can be seen as part of a data filtering framework as Windisch et al (2011) formalize it in three hierarchical layers, i.e. (1) neutral layer, (2) domain layer and (3) application layer.

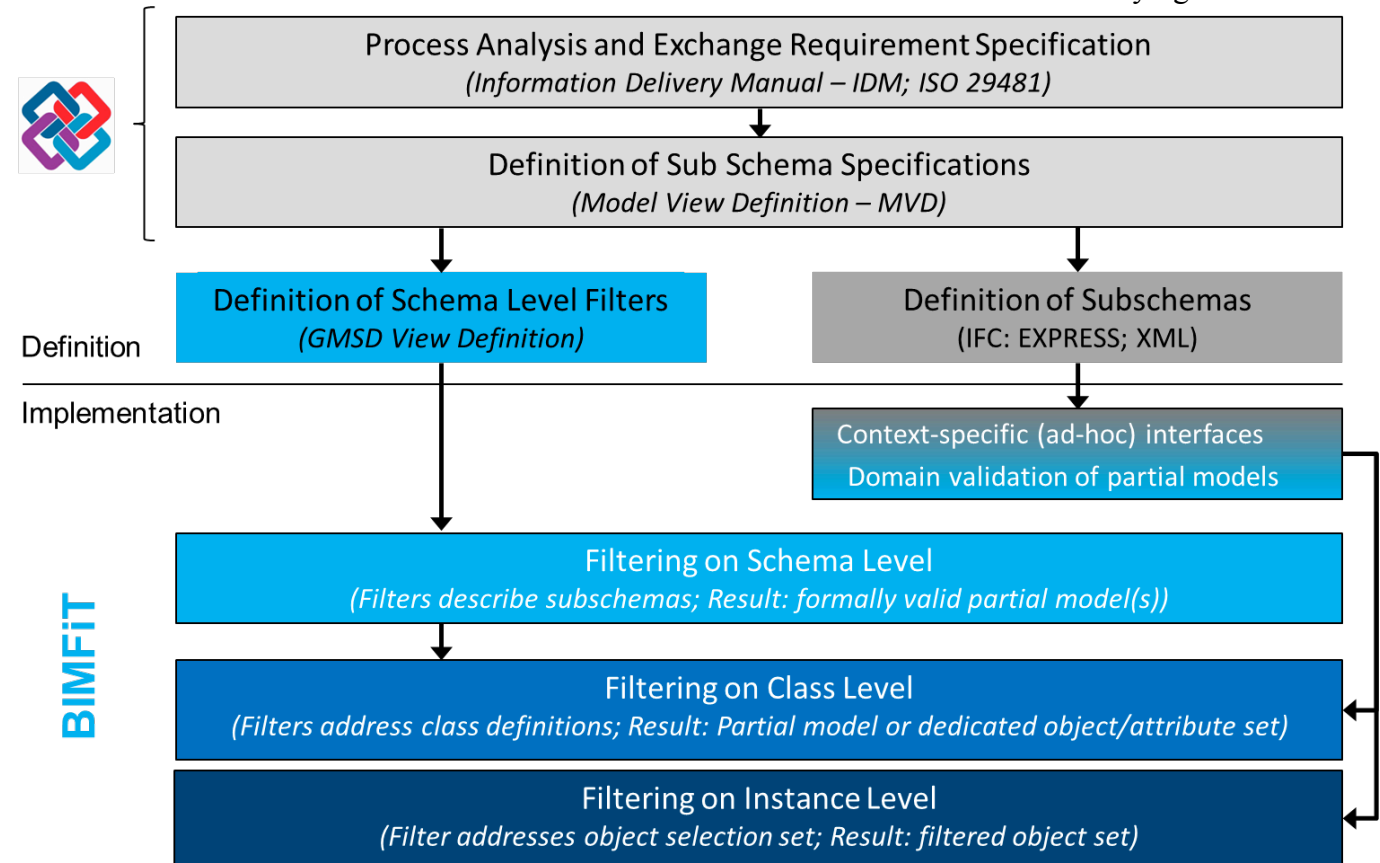


Figure 2: IFC-based data filtering with BIMfit

The application layer forms the interface to the end users. It provides necessary functionality for a specific application and invokes functions from the domain layer. The domain layer is managed by software developers. It contains domain specific functions, like filter functions for the BIM architecture model, and it uses functions of the neutral layer.

The base functions of the neutral layer will enable a consistent model access by identifying, selecting, calculating or manipulating the data (objects, attribute, relations etc.) needed for a domain and application specific filter task. The implementation of the core services will be made by extending the BIMfit tool, which was partly developed in the European projects HESMOS (HESMOS 2010) and ISES (Katranuschkov 2013). As represented on figure 1 the goal of BIMfit will be to access the data at different hierarchical levels of the model with respect to the exchange requirements expressed in Model View Definitions (MVD).

The core and data management services will be driven by the design workflow which will be mod-

eled on the basis of the new HOLISTEEC design methodology. More specifically the services outputs will be controlled by the exchange requirements that specify the data to be delivered to each simulation and to any business application. The BIM Lifecycle Information Framework will implement the design workflow. In this sense it will be responsible for the orchestration and execution of the data management services as well as their underlying core services.

5 BIM LIFECYCLE INFORMATION FRAMEWORK

BIM Infrastructure considers the static with of the data model, BIM Lifecycle Information Framework deals with the dynamic management of these data during the entire life-cycle, providing high-level services to enable a collaborative and cloud-based building design process and achieve the interoperability of tools, domains and scales.

The information of a building design constantly evolves and the number of actors and interaction levels greatly varies, leading to inconsistencies and discontinuities in the information flow which hinder a successful project management and the achievement of the desired performance targets.

Taking as input the gap analysis of current design methodologies and the requirements expressed by end users a set of BIM views and exchange requirements will be created which will be formalized using buildingSMART standards such as Information Delivery Manual (IDM) and Model View Definitions

(MVD). The aim is to identify and formalize interactions with the model:

- What data is exchanged and the level of detail required
- When it is needed during the life-cycle
- Who accesses the information

The innovative feature of the life-cycle information framework resides on the proper addressing of two crucial aspects:

- Different mutually dependent analysis requirements are considered since early stages (energy, lighting, environmental, acoustic).
- Building/urban data interactions and mapping are covered

In this way, the implementation of this collaborative framework will ensure that, in all decision points of the design process, required data to support such decisions is always on the cloud, with smart multi-scale and multi-physical synchronization mechanisms that guarantee the interoperability of the different views and interpretations of the model.

The development of an IFC compliant e-Catalogue, focused on envelope systems will also take into account this multi-domain coupling.

Multi-scale interoperability will be achieved by means of a link between BIM and GIS models, addressing the interoperability of IFC and CityGML standards. Urban-scale phenomena (shadowing effects and reflections of surrounding buildings, noise exposure, lighting and reflections...) will be correctly mapped to the building, yielding a neighbourhood-aware building simulation.

A set of BIM Management services will be implemented to properly address the data searching, filtering and updating, ensuring the traceability of changes and permissions and responsibilities associated to every decision.

means of effective collaboration and enabling a smooth transition for novel design methodologies.

A set of plug-ins will be developed to extend existing tools capabilities at building (CAD, engineering) and district (GIS) level, particularly those provided by partners in the project. These plug-ins will steer the process of BIM and neighbourhood data management and cloud synchronization.

On the server side, a set of platform-independent services will be developed based of W3C and OGC (Open Geospatial Consortium), with clearly documented interfaces, guaranteeing the evolution of the platform and future connection of additional third-party tools. The openness and contribution to standards and interoperability is one of the key technological objectives of HOLISTEEC.

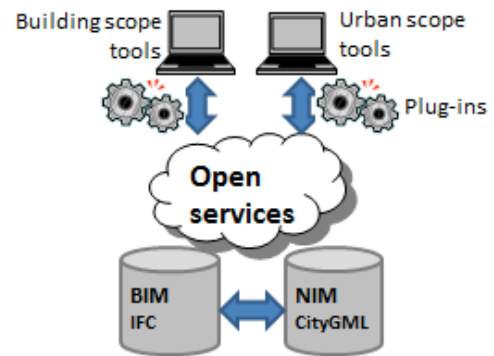


Figure 4: Client-server view of HOLISTEEC Platform

Finally, on top of core and data management services a set of high-level services will be developed, also based on standards and oriented to business needs, for example services to rate or benchmark a building, to provide results of different scenarios simulation and indicators. Visualization services based on Web3D standards are also foreseen, which will be consumed in the user-interface to be developed for the multi-criteria analysis.

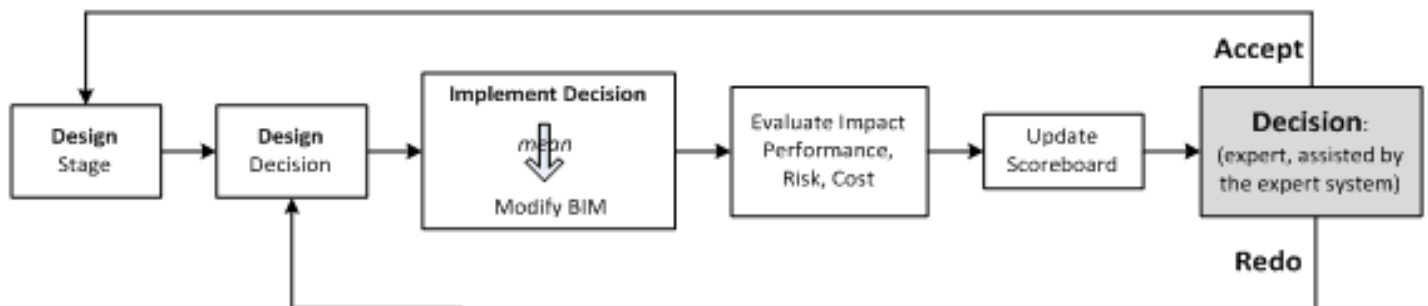


Figure 3: Loop approach in HOLISTEEC Platform

This will lead to an effective transition from traditional sequential design to a loop-based approach of the workflow, suited for a what-if analysis, where potential risks of a decision and implications in other domains have to be considered beforehand.

HOLISTEEC platform will be seamlessly integrated in current end-users' workflow, adapted to support existing methodologies, but creating new

6 MULTICRITERIA DESIGN OPTIMIZATION TOOL

A major goal of the HOLISTEEC project is the development of a building design decision support tool, relying on advanced artificial intelligence techniques and on the multi-physical simulation engines, able to provide semi-automated, focused, assistance for fast and optimized design decisions. Simulations

engines will cover the following aspects: energy related to the building and the building neighborhood, acoustics, lighting, and environmental impact.

6.1 Tool and User interface

Providing stakeholders with a “dashboard” allowing visualizing at any time and in an intuitive way various performances and indicators of the project thus supporting what-if scenarios to test design alternatives is of great importance. Visualization will support both 2D and 3D modes in order to allow users to locate the part of the project that is considered and then to inspect various physical components and systems even those that are hidden (various layers in wall, electrical network, etc.).

A specific dashboard will be provided in order to allow the user to have at a glance the big picture of the performances depending on the focus of the user (energy efficiency, acoustic performances, lighting, environmental impact, etc.) and the chosen design options. This will also facilitate the comparison between various design options where a global optimum is required between various technical domains.

6.2 Simulation Engines

The building energy simulation engine will include a “standard” building thermal conception approach but also the local environmental effects on building energy performances. Indeed, shading of neighboring buildings, daylight reflections and radiative transfers between structures, local air temperature variation as a function of wind properties, impact of vegetation should be issues taken into account for energy evaluation.

The acoustic simulation engine should allow to predicting the acoustic performance of a complete building based on the statistical energy analysis similarly as the current approach in the EN 12354 standard series. This simulation engine tool will focus on the airborne and impact sound insulation, absorption area and reverberation time of rooms, airborne and structure borne noise from service equipment.

The lighting simulation engine will cover artificial indoor lighting related to the available fluxes from outdoor taking into account masking effects produced by neighboring buildings and daylight reflection from neighboring façades, and the control system involved. Visual indoor comfort as well as the energy consumption of the electrical lighting equipment will be evaluated. Furthermore, the available energy from Solar Renewable Energy (SRE) systems related to the sky conditions and the masking/contributing effects of the neighborhood will also be estimated.

The environmental impact simulation engine should quantify all environmental impacts of a

building at the neighborhood scale during the life-time cycle of a building. It will be based on the EN 15804 standard, and will allow including new contributors such as people transportation and new advanced parameters for example the wear of materials due to the outdoor conditions.

From BIM/IFC model, model adapters and transformers will have to be developed for these different simulation engines.

6.3 Multi-criteria analysis for assisted optimization

An integrated service for multi-physical building analysis, enabling fast, reliable and holistic assessment of design choices has to be developed. The multi-physical simulation engine will be completed by a design assistant, providing online recommendations to the designer, enabling a semi-automated approach to design.

Cost and risk analyses will be performed at different levels of detail regarding the design stage. According to the holistic nature of the new design methodology costs will have to encompass construction and exploitation costs including energy costs. The purpose of the risk analysis will be to assess the possible deviations on the performances (cost, energy, acoustic, etc.) induced by the risks identified in several domains and stored in the integrated BIM. Thus this will provide risk level indicators for each design alternative. As risks are by nature uncertainties in the data model, the expert system should allow the end-user to check the effect of some specific risks by manually varying their related data, but also to analyze huge amount of risks. For this purpose uncertainty (Monte-Carlo, Latin Hypercube simulations) analyses will be performed with the help of existing solvers and if needed corresponding algorithms will be implemented in the expert system.

On the decision level the application of approved approaches considering uncertainties (e.g. fuzzy) in multi-criteria decision-making will be assessed and if appropriate applied. This will allow the design assistant to make recommendations about alternative designs that on one hand optimize the performances of the project with regard to the incompleteness of the model in early design stages, and on the other hand proactively or reactively treat risks.

7 CONCLUSION AND PERSPECTIVES

This paper has given an overview of the HO-LISTEEC platform, as envisioned in the preliminary design phase. The architecture of the platform is based on a 3-layers pattern, which enable for a better separation of concerns between low-level data modeling and management issues, life cycle services provision, and decision-making support / end user interfaces. The aim of the platform is particularly to

address seamlessly the various interoperability leaks that dwell from the heterogeneity of data and tools involved in the building life cycle – an issue that has been recognized as specifically critical by the end users involved in the project. For this purpose, the design relies on a combination of proven, recognized data modeling standards, and proven tools and simulation engines, which are bridged together to form a consistent and extensive support. It is expected that this approach will be effective in enabling decisive advances in the field of BIM-aware design support tools.

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