# Functional Requirements and System Architecture for Decision Support of Energy Efficient Building Design in Retrofit and Maintenance Stage

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## Abstract

This paper describes development of a methodology to support better retrofit and maintenance with optimised energy consumption using evolving technologies in material, components and systems both at building and neighbourhood levels. It is based on a retrofit and maintenance scenario focused on specification of the functional requirements, databases requirement and system architecture for the construction and operation of the decision support tool. Decision support (DS) tools have already been developed for architects and building designers to choose best building design options with retrofit and maintenance in mind. However, there is a lack of understanding of the required data structures, databases, definition of the functional requirements and the variety of the possible system architectures for this application. The proposed DS tool will support Facility Management (FM) to design their option on Building Information Model (BIM) file by making best retrofit and maintenance decisions for improved energy efficiency (EE) without needing full knowledge of the latest technologies in any required subject and without being expert in building energy performance analysis and simulation. A detailed retrofit and maintenance scenario and its corresponding process map are developed and explained in details. Database requirements are extracted and discussed, leading to specification of the necessary structure and content with a level of details. The functional requirements for retrofit and maintenance design scenario are discussed and an exhaustive list is generated. The decision support tool was structured using four building blocks: (i) energy performance and simulation block; (ii) retrofit and maintenance options generator; (iii) optimisation block and; (iv) a decision making block based on Multiple Criteria Decision Making (MCDM) method.
**Keywords:** Decision Support, BIM, Building Energy Performance, Retrofit and Maintenance.

# 1. Introduction

This paper describes functional requirements and system architecture for decision support of energy efficient (EE) building design in retrofit and maintenance stage. Decision support (DS) tools are becoming more and more necessary for architects and building designers to make best energy efficient (EE) design decision, and support retrofit and maintenance projects (Ferreira et al., 2013). However, little has been done to identify the databases requirements to enable EE design that does support FM during operations. This paper draws the stages of the process for design of a decision support system including its required databases and decision making criteria. Functional requirements and system architecture are also elaborated in details toward development of the proposed DS tool. This is aimed to support facility management (FM) to design their maintenance or retrofit option on building information model (BIM) file through making best decisions for improved energy efficiency (EE) without being experts in the latest technologies of the required subject or being experts in building energy performance analysis and simulation. The necessary tools' architecture includes the alternatives generator tool, the energy performance assessment tool and the DS tool.

In order to achieve sustainable development of our society, retrofitting existing buildings to improve their energy efficiency has become an inevitable task for the government of several countries (DOE, 2009), (Green Deal, UK GOV), (CBRE, Retrofitting Existing Buildings). Generally, a sustainable building retrofit programme consists of five key phases, from the project setup and pre-retrofit survey phase to the validation and verification phase (Ma, 2012). In this process, identification of retrofit options using reliable data is essential for a successful building retrofit project. To provide reliable evidence for selecting suitable retrofit measures, dynamic building performance simulation tools, such as TRNSYS (Santamouris, 2007), EnergyPlus (Chidiac, 2011), (Wei, 2014), (Ascione, 2011), IES VE (Ben, 2014) and DOE-2 (Zmeureanu, 1990), have been used widely in real projects. Design4Energy (D4E) is an on-going EU research project, consisting of 17 partners from several countries in Europe, such as Spain, UK and Germany (Design4Energy). The project is aiming to develop an innovative Integrated Evolutionary Design Methodology, which can allow the stakeholders to predict the current and future energy efficiency of buildings and make better informed decision in optimizing the energy performance during the building life cycle. The work presented here is particularly focused on retrofit and maintenance stages. Within D4E a novel decision support tool based on dynamic building performance simulation therefore is being developed, and it meant to first be usable for building retrofit and maintenance projects to help stakeholders choose the most suitable retrofit/maintenance measure(s) for their projects (Fouchal, 2014).

The main decision making process focuses on using building simulation to predict the effectiveness of various retrofit or maintenance measures (alternatives) and inform the current development of a dedicated decision support tool for FM. Also the system relies in particular on adequate definition of database requirements in terms of components, parameters and indicators to automatically generate all possible retrofit or maintenance options. A set of databases are being developed for the decision support tool, this development includes identification of the requirements for IT systems, components, energy systems and, materials. Analysing existing database solutions was the first pre-requisite, then identification of databases' characteristics using focus groups of potential users (architects, energy designers and FM) and finally tuned to suite the type of decision support tool being developed. Decision support tools have been key in the providing smartens of many design platforms for building practitioners, the system architecture in question here is the main engine of the Design4Energy (D4E) platform (D4E, web1). These platforms do provide basis for collaboration and knowledge sharing with updatable databases. The value of design platforms is in their workflow speed and quality, facilitating team contribution integration, and rapid feedback on energy performance (NREL's OpenStudio, June 2015). OpenStudio started as an open source project to create a collection of

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software tools for energy modelling. For these platforms databases is essential for their functioning. While xBIM is another open source development platform, which allows creating application for BIM based on the IFC standard (xBIM, June 2015). TNO BIM Server is another open source development platform, which allows creating application for BIM based on the IFC standard (bimserver, June 2015). The Building SMART Data Dictionary (bSDD) is a reference library or a framework that aims at supporting improved interoperability in the building and construction industry. It can connect software applications to product databases or attach specific attributes to construction designs. These references can include information from a product manufacturer, typical room requirements, cost data or environmental data (ifd standards, June 2015), (ifd-library, June 2015).

Multiple Criteria Decision Making (MCDM) integrates multiple indicators into a single meaningful index to allow ranking and comparing options for decision making, see figure 1 (Fouchal, 2015). It is an efficient statistical method to combine component indices arising from all the information sources into a single overall meaningful index, therefore ranking and comparing are feasible. MCDM has the ability to weight different alternatives and make judgement on various criteria for possible selection of the best/suitable alternative(s). A typical MCDM problem is when there are a number of criteria to assess a list of alternatives. Each alternative is represented by a single value for each of the criteria to permit the assessment and/or ranking, see figure 1. Complex decision requires consideration of multiple criteria (Zeleny, 1982).

Analytic Hierarchy Process (AHP) method as proposed by Saaty (1994) that is based on priority theory decomposes a complex multi-dimensional decision making problem into a system of hierarchies. It uses the relative importance of the alternatives in terms of each criterion. The AHP has the ability to logically incorporate data and expert's judgement in the model for measurement and prioritising intangibles. As a complex and unstructured situation is broken down, its components are arranged into a hierarchic order including criteria and alternatives.
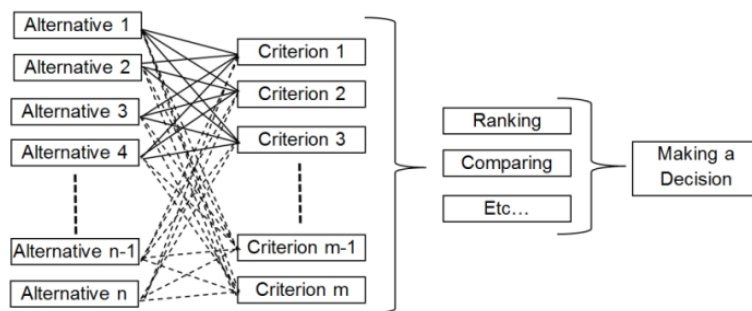


*Figure 1 Multi criteria decision making (MCDM) process being adopted in D4E*

Component catalogues relational databases are accessible through internet protocols. The Building Component Library (BCL) by NREL provides searchable information about EE related technologies and a list of measures to meet energetic issues (Fleming et al., 2012). The included information can represent physical characteristics of buildings such as windows, walls, and doors, or can refer to related operational information such as occupancy, equipment schedules and weather information. Each measure and energy system can be downloaded as a XML, RB and OSM file describing these components (bcl.nrel, June 2015). Data Repository ISES is another cloud-based data repository. It contains information such as climate data or stochastic templates but most interestingly energy product and material catalogues containing energy properties of products and materials (ISES D4.1, 2014). The library uses the PLIB ontology model (based on ISO 13584). All information is saved in the ifc file format (ISES D4.3, 2014). The MagiCAD Product Database is a product catalogue or database that contains

over one million products from over hundred manufacturers. A designer can choose components through a plugin directly via the CAD-tool interface. This interface is connected to a plugin on the manufacturers' site (MagiCAD, 2014).

In the following sections are presented the retrofit and maintenance scenario, the process map, the functional requirement and database requirement to finally develop the system architecture for the decision support tool.

## 2. Retrofit and maintenance scenario

A detailed retrofit and maintenance scenario is developed and described here; the corresponding process map is also developed and explained in details in the section to follow. The scenario starts with the facility manager evaluating the operation stage and maintenance data of an existing building and reveals some building performance changes which require serious attention such as undertaking some repair or upgrade to the building. An architect takes over and starts analysing historical data of operation, maintenance records as well as user behaviour data, monitoring data, the map of neighbourhood energy nodes and cost data. From this analysis it becomes apparent that some of the data is not compatible with building's energy anticipated performance. He/she therefore request a thorough investigation of the causes of the energy consumption mismatch with original design in specific parts of the building which involves the heating system (Wei, 2015). A heating system expert is called in and identifies an old boiler as the source of the problem. The architect in collaboration with a building services engineer sketch a retrofit or maintenance design using a BIM model on the D4E platform. In doing so, the architect takes into consideration a number of parameters such as the local weather profile, facility management reports, financial status of the building owner and looks into other case studies to decide the best option forward for optimisation of energy level ahead of the conceptual design completion. At this stage, the architect considers the market and the various options for the energy performance of the project's life cycle and cost of future operation and maintenance to prepare to discusses various design options with the client to make a decision.

Mainly two routes become possible depending on the budget in hand and existence of information on new source of district heating to become available in the near future within the vicinity of the building. These options are analysed and evaluated by the designer comparing the retrofitting improvements versus maintenance action. The D4E platform supports the designers by highlighting critical building zones. The designer can filter out the existing building data for transferring them to certain design tools (CAD, etc.). Using the different design tools the designers can develop retrofitting variants for further integration and analysis in the collaborative platform. The simulation tool integrated in the system enables running a number of analyses to assess the impacts of the proposed retrofitting or maintenance variants on the energy efficiency and compare them to historical data of similar existing buildings. The design is then passed on to the mechanical and electrical engineers as a BIM model. The 3D collaborative environment provides them the possibility to explore what-if-scenarios, they can drag components from the database library to modify and optimise the design. Furthermore the platform provides them with cost estimation of the different options on different terms (short to long). The information required during these activities will be stored into a common database.

## 3. Process map

During the operation of the building the stages described in figure 2 are followed. The process of identifying building issues during the operation phase are described, where the building's under-performance is identified and adequate measures are undertaken through D4E platform.
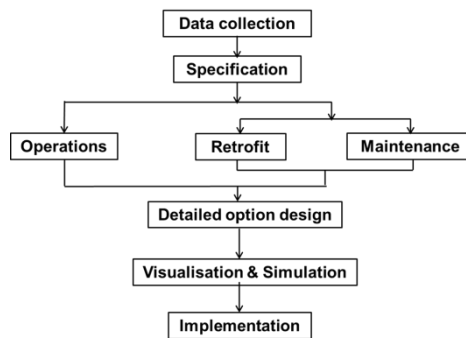
*Figure 2 operation of the building including retrofit or maintenance*

However, the process map being developed has no specific focus in terms of the type of the building requiring retrofit and maintenance. It is developed on a higher level and aims to cover all possible requirements of domestic and non-domestic buildings. However, in the case of industrial and buildings with specific uses (e.g. health care centres) adjustments would be required for the process map to be applicable, including the need for appropriate population of the databases with relevant information. For the purposes of this research, to verify the retrofit and maintenance process proposed and to validate the decision support tool, a case study of 20 domestic buildings is used. The main limitations and potential of the developed tool are highlighted. Additional testing of the decision support tool would be required to further validate its applicability in different types of buildings.

## 3.1 Monitoring building operation (client & FM):

During the operation stage of a building the client (user/owner) and the facility management team undertake scheduled monitoring and/or observation of the building performance, generally using electronic monitoring devices such as energy meters, which measure the energy consumption and store it periodically into a file using common format such as Excel. The operational monitoring data are produced in the form of sensor data (of energy systems, of energy used by equipment, user behaviour, indoor air quality and moisture level), operation bills (of energy/utilities) and maintenance/repair bills. The client gets signals from daily use and observation of the building behaviour in terms of indoor air quality (e.g. thermal environment, visual environment and acoustic environment), sensors/energy monitoring data and operational cost. If the building's indoor air quality level and moisture level have changed it may suggest that the building envelope or the energy systems have changed in a way that is not expected. Furthermore if the operational cost such as the energy bill has changed similar cause may apply. Under this kind of circumstances the client reports any observations to the facility management team. Similarly the FM team can make similar observations from the available monitoring data or studying reports from the client (written, emails or verbal), see figure 3. The data collected can be clustered as: (i) Building survey; (ii) Sensors and monitoring data; (iii) Client report & user interview; (iv) Review of maintenance strategy; (v) Access BIM files / As built drawings.
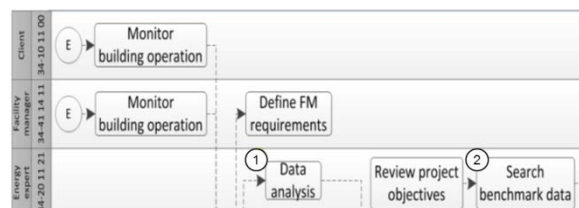


*Figure 3 defining the need for retrofit or maintenance*

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## 3.2 Requirement, data analysis and review of project's objectives

Based on operation data the facility manager defines their requirement to re-establish the normal operation of the building or to upgrade the performance level for example to comply with new regulations or simply respond to the client request. The energy expert and other energy system experts such as HVAC engineers will use Tool 1 to assess the reported building energy performance issue and set targets for remedy or upgrade. The target setting will involve selection of key indicators and defining the operating ranges for each indicator. The energy expert reviews the objectives traced to meet the use and operation needs, these are identified on the basis of the FM requirements and the expected energy performance of the building.

## 3.3 Search benchmarks and finalise key target setting

The benchmark browser and search tool will be used to set the benchmarking related targets. The standard methods and benchmarks for consideration in this project include CIBSE (Chartered Institute for Building Services Engineers) TM22, TM46, TM39, TM46 and TM 47, the AM11 Building Energy and Environmental Modelling (BEEM) (CIBSE Applications Manual 11) and the EPBD (Energy Performance of Buildings Directive), IPMVP (International Performance Measurement and Verification Protocol) in the USA, as well as the Performance Contracting Program standards ISO. Setting key target levels will be based on benchmarks and client requirements by setting the range extreme boundaries for each indicator being.

## 3.4 Retrofit or maintenance options generation and selection

Choosing of energy options, then run a feasibility study and produce a feasibility report for retrofit and maintenance will be carried out by the energy expert first through selecting variables to be used to form the options, see figure 4. These variables will be displayed to him/her under a list of drop down menus providing all possible and available variants of each component or action to incorporate of performed. This process will be possible by manual generation of options by the energy expert using a set of integration parameters which help to combine the variables in various ways to produce a list of possible options with potential to achieve the targets being set.
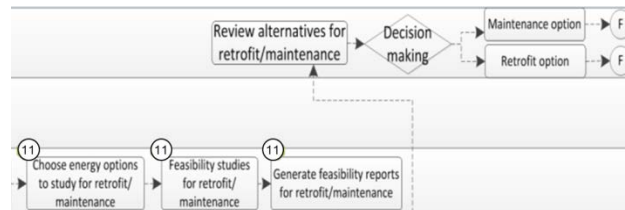


*Figure 4 decisions making on whether to do maintenance or retrofit*

The energy expert will use new methods to verify the process and the generated options while still having the power to alter the process of selection or add/reduce possibilities.

## 3.5 Decision making by the client and Produce of retrofit brief

At this point of the process a review of alternatives will be undertaken by the client using the decision support tool 11 to make an initial decision which is more suitable for the project, maintenance or retrofit. The feasibility results will be prepared in a format that will simplify the decision making of the client.

If decision is to retrofit, a model has to be created. It starts by the client producing the brief which contains the expected energy performance, the KPIs and setting up the targets. The next step is defining the specification of the ideal solution in relation to the given client requirements.

## 3.6  Creation of retrofit alternatives concept designs

The remaining stages of the model will be completed by an Architect who will conduct an environmental analysis and building performance assessment. The architect generates a project program. Using Tool 4 which is the BIM design tool he/she sketches the spatial outlines of the retrofit alternatives onto the existing BIM data on the basis of the defined indicators. The produced LOD4 models will be analysed by the architect taking into consideration the site implication and adaptability to the surrounding.

## 3.7  Improve retrofit model

The BIM model is then improved with material data for better energy efficiency performance and $CO_2$ emissions reduction. In this phase the architect takes into account the embodied energy of the materials, use recyclable materials whenever possible, introduces new materials, figure 5.
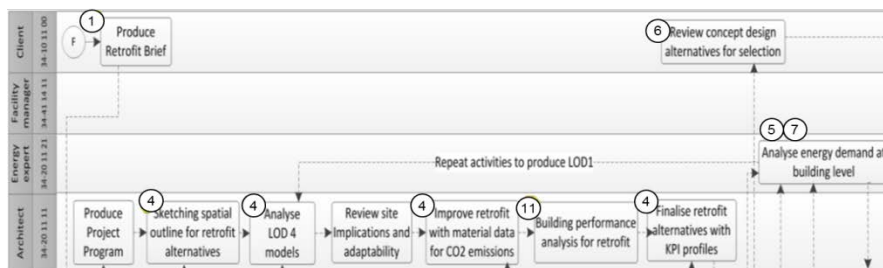


*Figure 5 modelling of the retrofit alternatives and undertaking of performance assessments*

## 3.8  Performance analysis for passive design

The architect has the option to choose to undertake some building performance analysis under the proposed retrofit alternatives using the energy efficient BIM. This procedure will mainly help to reduce the number of options that can be considered and even provide enough information to make the ranking on the basis of the chosen criteria from the list of the performance indicators. This procedure is conducted via the decision support tool 11 which is built on the top of an energy simulation tool, such as EnergyPlus, which is one of the most popular tools for dynamic building performance simulation. The decision support tool will perform building performance simulations to all possible retrofit scenarios preliminarily defined by the client and rank them using the chosen selection criteria.

## 3.9  Design concept and review by client

The architect finalises design alternatives with KPIs profiles using BIM and generate a design concepts for each potential alternative. Through the collaborative environment Tool 6 the client reviews the produced design concepts taking into consideration of his/her main requirements which include energy consumption, the construction cost and LCC.

## 3.10 Analysis of energy demand and Analyse energy alternatives at neighbourhood level

The energy expert will conduct an analysis of building energy demand using the energy simulation performance tool based on eeBIM Tool 5 and the energy match optimiser tool 7. Following this analysis the client via the collaborative environment will review of energy options for the selected retrofit options and narrows down the number of options which would be passed onto the architect on the collaborative environment Tool 6 to verify the BIM models of the selected alternatives in term of their energy matching potential. The energy expert will analyse the remaining retrofit alternatives from the previous steps for their higher potential to address the requirement already specified in the project and the pre-set targets using the target setting tool 1. The aim of this run of analysis is to evaluate the energy matching at neighbourhood level and rank them in their order of potential offered by each using a set of indicators which include energy price mode, renewable energy that is available or/and potential in the coming future and the existing or potential for energy production. At this stage the architect on the collaborative environment will review using the updated BIM models (with embedded energy matching results) with selected alternatives for their energy matching potential at neighbourhood level.

## 3.11 Final approval of selected alternatives by client

The improved BIM models for the selected retrofit alternatives will be accessed through the collaborative environmental tool 6 by the client for final approval. At this stage if there is more than one alternative they will be listed in a ranking order on the basis of the most important indicators to the client to enable fast approval. If the decision that all requirements are meet by one alternative, it is then final approved and the corresponding concept design is also approved.

## 3.12 Maintenance options and analysis of maintenance options

If the initial review alternatives (at defining the options for retrofit or maintenance stage) by the client using the decision support tool 11 has resulted that maintenance is the most adequate approach to follow then a number of maintenance alternatives will be generated. The FM will lead this activity and start by analysing the LOD4 BIM model. Originally the feasibility results (Retrofit/maintenance) are prepared in a format (ranked on the basis of most important criteria only and presented it on the collaborative environment at high level of information only) to simplify the decision making of the client. The FM will study all the maintenance options that can be considered. He/she will check the potential for site implications to identify the metrics for the relevant indicators. The ranges for these indicators will be used together with the indicators for energy matching at both building and neighbourhood levels, complying with existing regulations and the client requirements. The decision support tool 11 with its energy simulation feature will be used to analyse the building energy performance, shown in figure 6.
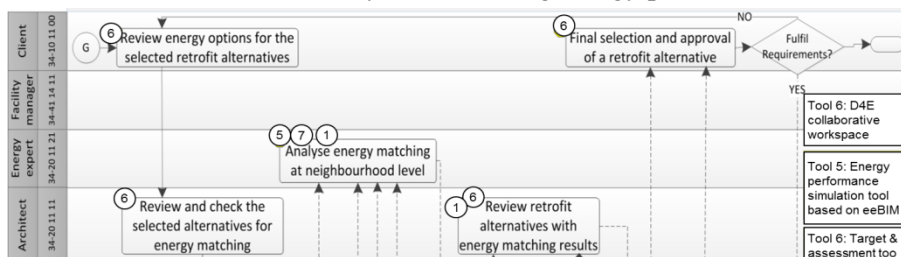


*Figure 6 checking the retrofit solutions and evaluate the energy matching potential*

## 3.13 Selected options, review by client and ready for execution

Key performance indicators will be used to narrow down the maintenance alternatives. Maintenance solutions will provisionally be ranked on their performance feasibility.
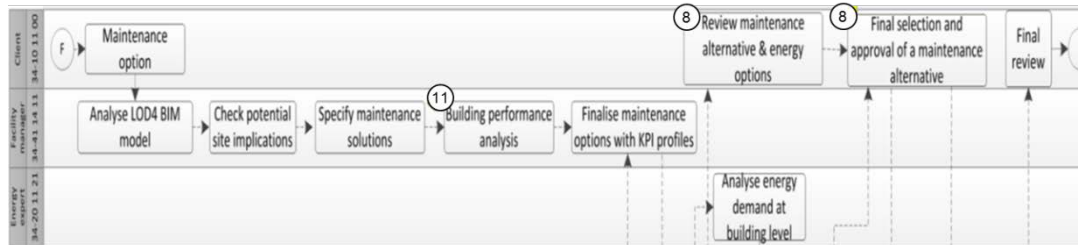


*Figure 7 studying of maintenance options and making final selection*

As shown in figure 7 the client will use the collaborative environment Tool 6 to review the maintenance alternatives and the energy options that are made available by the FM study. At a high level of information the client review will consider the analysis provided by the energy expert on solutions for their potential of reduced energy consumption, cost and LCC, energy matching at building and neighbourhood levels. This review process will result in a single maintenance alternative being approved by the client. Through the collaborative environment tool 6, various experts that are relevant to the different components included in the final solution will be invited to access the BIM model which embeds the maintenance solution. The HVAC engineer will use tool 8 (BIM HVAC design and simulation tool) to analyse the final solution for its feasibility, compliance and adequacy to fulfil all relevant stake holders' requirements. Similarly the electrical engineer will use Tool 9 (BIM electrical design and simulation tool) to verify that the solution selected is adequate to respond to the identified requirements.

# 4. Specification of the functional requirements for DS tool,

The decision making in retrofit and maintenance projects is supported by the energy simulation and actions for environmental influence through provision of energy system performance data and physical characteristics of building materials; cost simulation over the life cycle through e.g. the provision of data from similar real cases; design process through possibilities to share design results; owners' decision through providing information on the utilization and sustainability aspects of existing components and energy systems; and FM decision in choosing the optimal action for the available boundary conditions. The functional requirements for retrofit and maintenance design scenario are discussed and an exhaustive list is generated. Most of these requirements will be focusing on components identification, compliance with regulations and how to undertake the adequate modelling and simulation for retrofit and integration. Table 1 shows the identified different requirements for the different users.

*Table 2 requirement for the different users*

| User | Function required |
|------|-------------------|
| Owner/Facility manager | Digital trading function |
| Architect | Decision support / optimisation function |
| | Energy simulation function |
| | Energy matching & consumption estimation function |
| Building Energy designer | Information acquisition function |
| Information exchange | Filtering data & interlinking function |
| | Interaction with 3D sketch service |
| Building energy designer | Neighbourhood information acquisition and analysis function |
| | Visualization functional module |

# 5. Databases requirement

These will be captured from: Original brief from clients; Assessed against: building regulations; building design standards from ASHRAE, ISO and CIBSE, or commercial building performance rating methods such as BREEAM and LEED. Furthermore, through engaging existing users in workshops or through organised surveys. Some relevant examples could be requirement for more double glazing to meet the new standards; measurement of air tightness; measurement of natural daylight; need for smartness to support day to day activities; review of design life of different components; analysis of sensors data. The methodology adopted to identify the DB requirements for FM decision support included: Questionnaires and interviews with relevant end users. 30 responses were collected from different sectors, see Figure 2 and 3. 23% are Architects and designers, and another 20% are technology and solution providers.
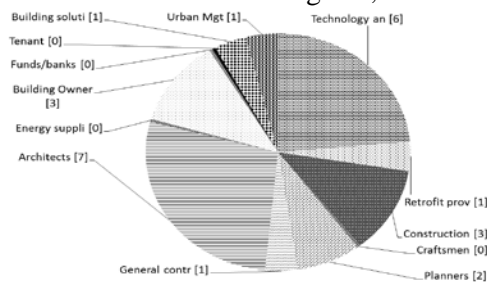



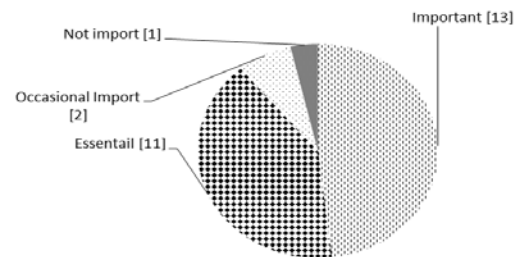*Figure 2 Stakeholders participation*          *Figure 3 Opinion on building component*

Building components initially have to be manually stored by users. The DB requirements as reported from the literature search included: (i) User, through interaction has to provide a direct link to BIM models; (ii) Visualising data, choices of building architecture; (iii) BIM models, have to be accessible by relevant stakeholders such as engineers for energy systems; (iv) Solutions with their operational attributes, maturity, deterioration, experienced costs or best practices of similar projects; (v) Material characterization (e.g. type, functionality, thickness, thermal conductivity, density specific heat, internal and external solar absorption, and emissivity); (vi) Team management.

## 5.1 Operation and maintenance data requirements

*Table 4 Indicators for retrofit and maintenance*

|    | Indicator |    | Indicator |
|----|-----------|----|-----------|
| 1  | Occupant involvement | 15 | CO2 reduction targets |
| 2  | Client awareness | 16 | ROI |
| 3  | Building performance assessment | 17 | Potential for energy generation |
| 4  | Building fabric assessment | 18 | Potential for natural ventilation |
| 5  | Building operational history evaluation | 19 | Potential for thermal energy (heat) recovery |
| 6  | Operations issue | 20 | EE potential of wall insulation thickness |
| 7  | Historic data analysis | 21 | EE potential of window glazing layers |
| 8  | FM reports quality | 22 | Lighting efficiency and control |
| 9  | Fault pin-pointing/detection | 23 | Boiler/central heating efficiency |
| 10 | Contractual arrangement | 24 | Compliance with regulation |
| 11 | Performance of Energy using Products (EuPs) | 25 | Refurbishment option ranking |
| 12 | Performance of Energy systems | 26 | Hot water generation & distribution system efficiency |
| 13 | Energy bills | 27 | Energy use vs. comfort conditions |
| 14 | Energy reduction targets | 28 | Client/user satisfaction. |

The methodology adopted to identify the database requirement in terms of design for operation and maintenance besides of review of relevant literature, included standards and guidelines to first highlight the generic domains of requirement. The survey was conducted with the aim of gauging more specific requirement to different usage groups on databases which will support design for building operation and maintenance. During a workshop with experts in retrofit and maintenance the database requirements are extracted and discussed leading to the specification

of the necessary structure and content with a certain level of details. Table 4 shows the list of indicators for retrofit and maintenance are used to characterise the requirements.

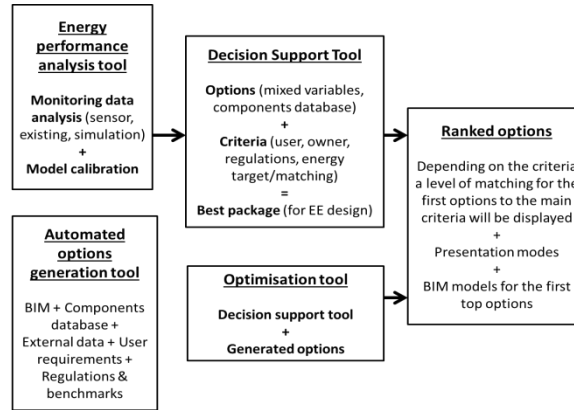# 6. System architecture of the decision support system



*Figure System architecture of the decision support system*

The decision support tool was structured using four building blocks which are: (i) energy performance and simulation block; (ii) retrofit and maintenance options generator; (iii) optimisation block and; (iv) the decision making block that is based on Multiple Criteria Decision Making (MCDM) method. Decision support tools have already been developed for architects and building designers to choose the best building design options with retrofit and maintenance in mind.

The proposed DS tool would support Facility Management (FM) to design their option on building Information Model (BIM) file through making best decisions during retrofit and maintenance for improved energy efficiency (EE) without having full knowledge of the latest technologies in any required subject and without being an expert in building energy performance analysis and simulation.

Within Design4Energy which is the sponsoring EU project of this work three architects and other end users of the retrofit and maintenance decision support tool are partners and are active members who were involved in shaping and testing the work being described in this paper. An initial exploration has also been undertaken with a larger number of external architects and facility managers to agree and feedback on the format and the content of the decision support tool and its corresponding components. At later stage of this development it is intended to embed it into a holistic design platform during which a program of validation and demonstration will be conducted with a much larger pool of end users.

# 7. Conclusions

An identification of the required data structures and databases to support designers and enable Facility Management (FM) to make decisions on best retrofit and maintenance for improved EE has been conducted. The databases requirements and functionalities have been detailed. A set of necessary databases were proposed to enable optimal decision making by FM and perform adequate design of new build. The level of detailing the database requirements is provided in terms of information technology (IT), components and systems, materials and the stakeholders. To complete the study a validation by FM of the database is conducted using the new decision support tool for maintenance and retrofit to be used. The work focused on using building simulation to predict the effectiveness of various retrofit measures and inform the current

development of a dedicated decision support tool for FM in particular definition of database requirements in terms of components, parameters and indicators to automatically generate all possible retrofit or maintenance options. Analysing existing database solutions was the first prerequisite, then identification of databases' characteristics using focus groups of potential users (architects, energy designers and FM) and finally tuned to suite the type of decision support tool being developed. Decision support tools have been key in the providing smartness of many design platforms. System architecture was therefore developed for embedding the set of decision making tools into the platform. A retrofit and maintenance scenario was used to follow through the decision making process for which the necessary tools were specified in terms of their functionality and then designed.

# 8. Acknowledgements

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