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DECISION SUPPORT TOOL FOR SELECTION OF BEST BUILDING RETROFIT ACTION

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Abstract: This paper shows a process of developing a decision support tool to automatically generate building retrofit alternatives and rank them using energy performance analysis, user requirements, relevant benchmarks and regulations. Refinement of the retrofit scenarios follows a set of steps from creation of a Building Information Model of a base-case representing the status of the building at the time of the analysis, then creation of combinations for the possible retrofit scenarios. TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) based multi criteria approach is adopted as it relies on identified best alternatives using selected criteria. Ranking of alternatives follows their relative closeness to the identified ideal alternative. Best options are graphically presented.

Keywords: MCDM, Building retrofit, BIM, decision support, energy performance

1 INTRODUCTION

Development of a decision support tool to automatically generate building retrofit advice for designers and architects, supported by building performance simulation and other user-centred design techniques is demonstrated. While considering stakeholders' requirements and benchmarks for reaching a final decision among automatically pre-defined retrofit combinations. In both this approach and those reviewed in the following section, the whole process as well as the final decisions are significantly affected by the experience and the knowledge of the building expert. Although their experience and knowledge are irreplaceable input to the whole process, development of practical tools to account for as much feasible combinations together with decision criteria as possible without pre-defined restrictions is key. Multi-objective optimisation techniques were found to enable reaching the wide coverage of all possible combinations; the proposed approach offers wide coverage by dynamic databases, self-learning and fast computing.

2 STATE OF THE ART

Efforts for effective improvement of the overall energy performance of buildings led to development of numerous methodologies. They all proceed by initial energy audits for estimation of the building's energy status and proposing evaluation of different scenarios regarding upgrade to a more energy efficient building. Among the early methodologies are: ''Tobus'', ''Xenios'' and ''Epiqr–Investimno'', introduced through

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the JouleII, Altener and Growth programmes (Balaras et al., 2002). For achieving the objectives set out by the EPBD directives, innovative tools were also developed, such as the ‘‘EPA-ED’’ and ‘‘EPA-NR’’, for assistance in energy audits and in support to designers and experts in buildings’ energy certification (EU Commission, 2006a). A ‘‘Datamine’’ database has also been created for collecting and storing data from the buildings’ energy certification in Europe (EU Commission, 2006b). Furthermore, computerisation has gradually been introduced into construction changing the way buildings are conceptualised, designed, built, operated, maintained and retrofitted (Eastman et al., 2011). More specifically building information modelling (BIM) is leading the change at every stage of the building’s life cycle orchestrated by a growing ICT community of practice (Dubé et al., 2011). The digital environment enabled by BIM allows numerous dynamic activities by stakeholders, including collaboration, information sharing and data storage throughout the building lifecycle (Succar, 2008).

Gero et al., 1983 were among the first to introduce a multi-criteria model in building design for enabling trade-offs between the building energy (thermal) performance and other criteria such as capital cost and usable area. Similar approaches have since been adopted by more scientists (Jaggs and Palmar, 2000; Kumbaroglu & Madlene, 2012; Diakaki et al., 2010). Kaklauskas et al., 2005, developed a multivariate design method and multi-criteria analysis for retrofit underperforming buildings, by calculating the significance, priorities and utility degree of various alternatives and ranking them. Allane, 2004 used a multi-criteria knapsack model to select the best retrofit option at the concept stage of the project. Juan et al., 2009, developed a self-learning driven decision support system for assessing housing condition and propose best retrofit actions taking into account trade-off between cost and quality. This comes with limitations as they are applied upon a set of predefined and pre-evaluated alternative solutions which are not holistic and exhaustive (Diakaki et al., 2008). The author investigated how multi objective optimization could support in improvement of the energy efficiency (EE) of existing buildings by maximising the possible number of alternative solutions and EE measures; showing that no optimal solution exists due to the competitiveness of the involved decision criteria. Multi-objective optimization is a scientific area that offers a wide variety of methods with great potential for the solution of complicated decision problems. Asadi et al., 2012 used simulation-based multi-objective optimization scheme (a combination of TRNSYS, GenOpt and a Tchebycheff optimization technique developed in MATLAB) to optimize the retrofit cost, energy savings and thermal comfort of a residential building. Alternative materials for walls insulation, roof insulation, window types, and installation of a solar collector were considered. The calculations were based on a multi objective algorithm for approximation in a wide and holistic account of all possible combinations to achieve the best retrofit option. Ibn-Mohammed et al., 2014 integrated economic considerations with operational and embodied emissions into a decision support for ranking of building retrofit options to effectively manage the reduction of lifecycle environmental impacts. Integrated economic and net environmental benefits and focuses on marginal abatement cost methods and Pareto optimisation.

The approach proposed in this paper uses multi-criteria-based decision making with potential for approaching near optimum solution as it is intended to use dynamic databases for the components alternatives and genetic algorithms for the self-learning combined with fast computing. However, in this paper the focus is only on demonstrating the capability of the proposed approach with minimum set of alternatives.

3 Research Methodology

The methodology starts with creation of a scenario for retrofitting using a process map developed over the life-cycle stages of the building. Functional requirements for the creation of the decision support tool (DST) and relevant supporting tools were generated from which a set of KPIs were derived. A survey with end users was also conducted to validate and enrich the KPIs selection. The DST tool is based on creation of a BIM file as the base case for the building then use of combinations of retrofit alternatives to be created by options generator which is intended to be based on dynamic databases. After filtering the alternatives using benchmarks information and the user preference in the form of weights the alternatives are ready for analysis. A set of algorithms are developed to calculate closeness of each alternative to an ideal solution.

3.1 Retrofit scenario design

Planning support tools for retrofitting for project managers, building owners, facility managers and building contractors can be made available as a desktop application or mobile apps to provide relevant knowledge and information such as project estimation (cost and time). There is no direct use of the tools for the building users apart from involving them in the planning stage of the work regarding their presence in the building and scheduling the work around their needs. In some scenarios the planning tool will have to deal with the occupant re-location during the retrofit implementation stage. The service offered through the tool to the user (project manager, facility manager and contractors) is first as a graphical interface and as a platform for interaction with the other relevant stakeholders including material and equipment suppliers and different fitters required for the job. The other services relate to activities for accessing stakeholders' diaries and the operations scheduling process. In addition to direct use by facility manager and projects managers there might be also an option that architects use the tool to readapt the design if required. The retrofit activities do mainly address old buildings that often do not have CAD or BIM models.

3.2 Functional requirements and KPIs

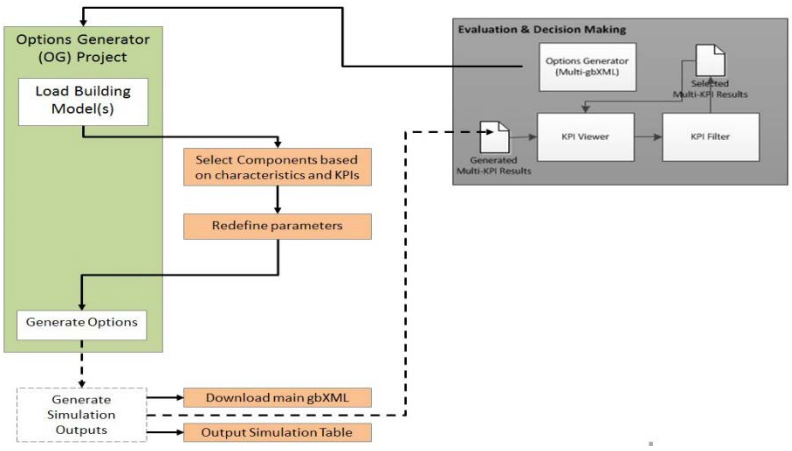

Figure 1 Decision making process

In the process map, for the retrofit scenario (Figure 1) a set of activities were identified, which were converted into functional requirements for designing the DST.

The list of functional requirements following the creation of the retrofit scenario and the process map includes: Generation of operation and monitoring data; Search benchmarking data; Specification of requirement for FM and client; Preliminary data analysis; Produce project objectives; Set key target levels; Create and describe all retrofit alternatives; Decision making to reduce the alternatives; Building performance analysis; Selection of energy options to consider for retrofit; Review alternatives for retrofit & make decision; Establish or review and update BIM model; Check for neighbourhood implication; Analyse energy demand at building level; Analyse energy matching at neighbourhood level; Energy demand calculation; Finalise retrofit options with KPI; Final approval of alternative; Generate final BIM models. The KPIs from functional requirements have been mapped against the KPIs shown in Table 1 created in a survey with 7 architects and 3 facility managers. The quantitative KPIs "Physical properties," "Comfort and wellbeing" and "Project management and operations have been suggested by the users in the survey, but only some these are indirectly are considered in the KPIs used in this work, such as comfort. The qualitative KPIs for each alternative are evaluated automatically without user interventions.

Table 1 KPIs for the design and usage of the decision support tool

PURPOSE	TYPE	KPIs
To prioritise for user (such as architect), owner and occupant To show on priority scale the combined preferences and wishes of all stakeholder	Quantitative	Energy performance
		Physical properties
		Economics / Cost
		Comfort and wellbeing
		Renewable energy systems usage
		Project management and operations
	Qualitative	Aesthetic and appearance
		Artistic or professional excellence touch
		Neighbourhood

3.3 Decision making and optimisation route selection

Selecting the multi-criteria decision making (MCDM) methodology for the retrofit started by determining whether the end-user's preferences will need to be taken into consideration or an automated process is preferred. In the case of the retrofit scenario the architect's and client's preferences play a key role and will need to be considered thoroughly. The method for representing the end-user's preferences is using relative weights for the identified criteria and the Key Performance Indicators (KPIs). The weights are determined by the end-users and their values are considered in the calculation of the KPIs for the proposed retrofit options. Thorough analysis of the environment and the criteria which govern the retrofit scenario created in this study led to narrowing down the theory to design the decision support tool using the technique for order preferences by similarity to an ideal solution (TOPSIS) (Agrawal, 2015). The TOPSIS methodology relies on the identification of the best retrofit alternatives generated using selected criteria. Ideal and negative ideal points are determined for the retrofit alternatives using the criteria for which maximisation or minimisation is required respectively. Ranking of the alternatives under exploration is provided on the basis of the relative closeness of each alternative to the identified ideal. Consequently, the ranking process proposed in this work not only differs from the aforementioned previous work by the weighting process of the KPIs made by the user but it attempts to guarantees the best EE alternative is identified. Contrary to the reported previous works which have some limitations as they are based on some predefined and pre-evaluated alternative solutions which are not holistic and exhaustive.

4 Development of the Decision Support Tool

4.1 Target setting

The target of the MCDM process for the retrofit scenario is set by the end-users, the architect and the client. The end-users' requirements are defined, quantified and stored using a designated graphical user interface. The targets are set on the basis of KPIs weights and acceptable ranges definition. The end-user plays an integral role in the Decision Making process. The user's preferences are specified as weights of relative significance for each of the KPIs of the retrofit alternatives' energy and cost performance. The weights assigned to the KPIs are specified on a scale of 0-100. The higher the weight assigned the most significant the relevant KPI is for the user. A weight equal to 0 indicates complete dismissal of the impact on the related criteria whereas a weight of 100 signifies prioritisation of the specific KPI. The weights are normalised across the six main KPIs and are ready for use by the ranking tool. To guide the user during target setting, appropriate ranges of acceptable values are identified for each of the six KPIs. For the definition of the range limits appropriate benchmarks are being used (Hyvärinen et al., 2016). The benchmarks relate to different levels of performance from A to E following the Energy Performance Certificate (EPC) rating scheme, with A and E signifying the best and least good performance. Based on the available information, the user can define the acceptable limits for the KPI values.

4.2 Retrofit and maintenance alternatives options generation

Automatic generation of retrofit alternatives is needed for an exhaustive search of appropriate retrofit options for the retrofit scenario under investigation. A number of combinations is proposed to be simulated and to calculate the KPIs for each possible alternative. Building components, HVAC systems and renewable technologies of various specifications are combined to provide the retrofit alternative options. A component database has been developed to store the information on various building components technologies. A tool has been developed (in C#) to create the retrofit alternative combinations by sourcing the building component parameter specifications of possible retrofit actions from the database. The Options Generator is developed to use the gbXML file (BIM export format) of the existing building (the building as-is before retrofitting) as the basis for creating alternative gbXML files representative of different retrofit options. The tool is able to identify the existing construction details contained within the gbXML file and modify or add elements to describe the effect of the retrofit measure applied. For the selected retrofit alternatives all possible combinations are being explored. Each retrofit measure will be combined with all applicable alternative measures except for those of the same type (e.g. windows will be combined with all wall types but not with other window types).

4.3 Key Performance Indicators calculation for each alternative

The next step of the decision making process is the calculation of the KPIs for each of the retrofit alternatives. A Building Information Modelling (BIM) to Building Energy Modelling (BEM) process has been developed consisting of a series of facilitating tools. The last tool of the process, the EplusKPI tool is used for the calculation of the KPIs. A BIM to BEM xml-based process is used which relies on the gbXML BIM export file (Dimitriou et al., 2017). Building survey instructions and design guidelines ensure that the gbXML offers an appropriate building representation. A series of tools developed (in VB.NET) bridges the data transfer gap between BIM (REVIT) and BEM (EnergyPlus). The tools developed offer editing capabilities for the gbXML file and a novel conversion method from BIM to BEM building representation. Using this process energy performance analysis can be performed for each of the retrofit alternatives. A tool has been developed (in VB.NET), the EplusKPI tool, to calculate the KPI values for each of the retrofit alternatives. The energy analysis results contained in the EnergyPlus output file (csv) and information stored in the BIM representation of the building are being used to calculate the thermal comfort, indoor air quality, energy consumption, CO2 emissions, Onsite Energy Ratio and Return on Investment KPIs. Table 2 shows an example of how the thermal Comfort KPI is calculated. To assess the thermal comfort, the min and max values of the operative temperature are identified using the EnergyPlus output variable 'Zone Operative Temperature' and are compared with relevant benchmark data. The lower and upper acceptable limits may vary depending on the building type and the comfort levels pursued. In the work done by Dimitriou et al (2017) further details on the level of detail required for the BIM model, the quality of data exported from BIM, interoperability issues observed in the BIM to BEM process and the necessary outputs from the BEM software are provided.

Table 2 Calculation example of the Thermal Comfort KPI

EnergyPlus output variable	Additional information required	Source of additional info
Zone Operative Temperature [oC](Hourly)	Lower and upper acceptable limits	Benchmark database

4.4 Ranking of alternatives

A ranking tool has been developed (in VB.NET) following the TOPSIS MCDM methodology to provide the ranking of the retrofit alternatives. There are two inputs to the ranking tool: the KPI values for all the retrofit alternative options that are within the user-defined range of acceptable values as specified previously; and the user-defined weights. Out of all the retrofit alternatives explored the best performing options in terms of KPI values are identified. The ideal and negative ideal points are determined as the options that present the maximum KPI values for the KPIs that need to be maximised (such as the RoI KPI) and the minimum KPI values for the KPIs that need to be minimised (such as the CO2 emissions KPI). The remaining retrofit alternative options are ranked in order of closeness to the ideal and negative ideal points using appropriate indexes. The output of the tool is an xml file containing the indexes calculated.

5 Testing in real-world building (GSM building)

Table 3 lists the retrofit alternatives which have been created for the GSM building which is a reference building selected by the partners in Design4Energy (design4Energy) project to simultaneously develop a set of tools that will be integrated in the single platform. Three retrofit alternatives are selected to test and showcase the decision support tool developed. The same retrofit alternatives have been used by architects to provide retrofitting support for the building under-study in a real-life scenario. These include the integration of photovoltaics and the enhancement of the building envelope using two different types of wall U-value improvement (Supafil34 and URSA Uberica 40mm). For each alternative the KPI values are listed in the table. The KPI values are used as the input to the MCDM TOPSIS tool to provide the ranking indexes.

Table 3 Retrofit alternatives for a real-world case-study

Alternatives	Thermal comfort (hours)	Indoor air quality (ppm)	Primary energy consumption per floor area (kWh/m2)	CO2 emissions (kgCO2/m2)	Onsite energy ratio (%)	Return on Investment in 30 years (%)
Photovoltaics	6659	412	242.63	58.05	0	52
Supafil34	6528	412	210.91	45.92	0	33
URSAUberica40mm	6613	412	229.64	54.55	0.47	11

Figure 2 is an extract from the prototype graphical user interface of the three alternatives as ranked by the tool. For each alternative the relevant KPI can be viewed using graphs that enable comparability across the different retrofit options. The GUI provides detailed results for each of the KPIs under consideration for users to critically assess the trade-offs between the different criteria for the selected retrofit options.

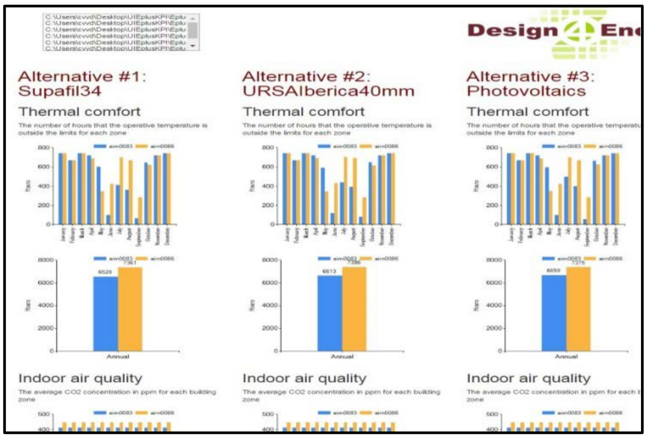

Figure 2 GUI for KPIs based on highest ranked retrofit alternative

6 CONCLUSIONS

A decision support tool to automatically generate building retrofit alternatives and rank them has been developed, the methodology undertaken was explained and the basis for creating the retrofit alternatives and ranking them were also explained. The concept is based on simulated energy performance of the building, user requirements, relevant benchmarks and regulations. TOPSIS methodology was adapted for identification of the best alternative based on a large pool of alternatives combinations and predefined target for the selected criteria. Ideal and negative ideal points are determined for the retrofit alternatives using the criteria for which maximisation or minimisation is required respectively. Ranking of the alternatives is based on relative closeness of each alternative to the identified ideal and presented on friendly graphical user interface.

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