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EUROPEAN UNION

Sudoe Stop CO_2

European Regional Development Fund

METHODOLOGY FOR ENERGY MANAGEMENT IN TRANSPORT STATIONS USING DIGITAL MODELING TOOLS

Low-carbon economy

Cooperation depends on you

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INDEX

SUMMARY

French

Le projet SUDOE STOP CO_2 vise à trouver des stratégies pour promouvoir l'efficacité énergétique dans les bâtiments des centres de transport (gares routières et ferroviaires) et ainsi réduire leur facture énergétique et leur impact environnemental.

Ce rapport présente une méthodologie innovante développée à partir de la recherche et du partage de connaissances pour l'amélioration de la gestion énergétique des gares, correspondant à l'objectif spécifique numéro 2. Il consiste en la stimulation et le transfert d'innovation, son évaluation et son application à l'amélioration de la performance énergétique des bâtiments du secteur des transports. Les résultats incluent la définition des exigences du modèle BIM, y compris les protocoles de transfert d'informations et le niveau de développement (LOD) à adopter.

L'analyse des études de cas développées dans le cadre de ce projet a permis d'établir le LOD pour l'analyse énergétique dans les bâtiments existants (centres de transport) et d'évaluer l'interopérabilité entre le logiciel de création BIM et celui d'analyse énergétique. Il a ainsi été montré que le LOD 300 est le plus approprié dans la plupart des paramètres liés à l'évaluation énergétique de ce type de bâtiment.

Cette méthodologie permet un processus décisionnel précis, afin d'identifier les solutions les plus adéquates à appliquer dans les projets de rénovation énergétique, incluant l'ensemble du processus, depuis l'acquisition de données, la modélisation énergétique, l'interopérabilité des logiciels jusqu'à l'analyse énergétique des bâtiments. Avec l'application de cette méthodologie, les avantages de l'évaluation de la performance énergétique du bâtiment dans un environnement virtuel peuvent être exploités dès les premières étapes du projet.

Portuguese

O projeto SUDOE STOP CO2 pretende abordar as estratégias de promoção de eficiência energética nas estações de transportes e consequentemente reduzir a fatura energética e o impacto ambiental destas infraestruturas.

Este relatório apresenta uma metodologia inovadora resultante da investigação e partilha de conhecimento e experiência para melhorar a gestão energética das estações e que corresponde ao objetivo específico número 2 do projeto, que consiste em estimular a transferência da inovação, a sua avaliação e aplicação à melhoria energética dos edifícios no sector dos transportes. Os resultados incluem a definição dos requisitos de modelação BIM, incluindo protocolos de transferência de informação e níveis de desenvolvimento (LOD) a adotar.

Através da análise de casos de estudo desenvolvidos no âmbito do projeto, foi possível estabelecer o LOD para análise energética em edifícios existentes (Estações de Transporte) e avaliar a interoperabilidade entre o software de criação de BIM e o software de análise energética. Foi possível apontar que para o tipo de edifícios em estudo, o LOD 300 é o mais adequado a ser usado na maioria dos parâmetros referentes à análise de energética.

A metodologia proposta permite um processo de tomada de decisão destinado à identificação das soluções mais adequadas a aplicar em projetos de reabilitação energética, incluindo todo o processo de aquisição de dados, modelação energética, análise de interoperabilidade análise energética do edifício. Com a aplicação

da metodologia, os benefícios de avaliar o desempenho energético dos edifícios num ambiente virtual podem ser aproveitados a partir das fases iniciais do projeto.

Spanish

El proyecto SUDOE STOP CO2 pretende abordar estrategias para la mejora de la eficiencia energética en las estaciones de transporte y, de este modo, reducir la factura energética y el impacto ambiental de estas infraestructuras.

El presente documento presenta una metodología innovadora resultante de la investigación e intercambio de conocimiento y experiencia para mejorar la gestión energética de las estaciones, correspondiente al objetivo específico número 2 del proyecto, que consiste en estimular la transferencia de la innovación, su evaluación y su aplicación en la mejora energética de los edificios en el sector de los transportes. Los resultados incluyen la definición de los requisitos de modelización BIM, aportando asimismo protocolos de transferencia de información y niveles de desarrollo (LOD) a adoptar.

A través del análisis de casos de estudio desarrollados en el marco del proyecto, ha sido posible establecer el LOD para el análisis energético de las construcciones existentes (estaciones de transporte) y evaluar la interoperabilidad entre el software de creación del método BIM y el software de análisis energético. Así, se ha concluido que, para el tipo de edificios analizados, el LOD 300 es el más adecuado para ser utilizado en la mayoría de los parámetros referente a la evaluación energética.

La metodología propuesta permite un proceso de toma de decisiones destinado a la identificación de las soluciones más adecuadas a aplicar en proyectos de rehabilitación energética, incluyendo todo el proceso de obtención y captura de datos, modelización energética, análisis de interoperabilidad y análisis energético del edificio. Con la aplicación de la metodología, los beneficios de evaluar el comportamiento energético de los edificios en un entorno virtual pueden ser aprovechados en las fases iniciales del proyecto.

English

SUDOE STOP CO2 project aims to address strategies to promote the energy efficiency of transport stations and, consequently, reduce the energy costs and the environment impact of these facilities.

This report presents an innovative methodology developed from the research and knowledge sharing for the improvement of the energy management of stations corresponding to the specific objective number 2, consisting of stimulation and innovation transfer, its evaluation and application to the energy performance improvement of buildings linked to the transportation sector. The results include the definition of BIM model requirements, including information transfer protocols and the Level of Development (LOD) to be adopted.

Through the analysis of case studies developed in the frame of this project, it was possible to establish the LOD for energy analysis in existing buildings (Transport Stations) and evaluate the interoperability between the BIM authoring software and energy-analysis software. It was possible to point out that LOD 300 is the most accurate to be used in most of the parameters regarding energy analysis in this type of buildings.

This methodology allows for an accurate decision making process, to identify the most adequate solutions to apply in energy retrofitting projects, including the entire process from data acquisition, energy modeling, software interoperability and building energy analysis. With the application of this methodology, the benefits of assessing the building energy performance on a virtual environment may be gathered in the earliest project stages.

1 INTRODUCTION

Most European cities have at least a bus or/and a railway station and many of these facilities have a high level of energy consumption and consequently a considerable impact on the surrounding environment. The growing awareness on the environment has resulted in a considerable number of studies that aim to find new solutions in order to reduce pollution and increase the quality of life of the population. Thus, in the context of the transport stations, the SUDOE STOP CO2 project aims to address strategies to promote energy efficiency in these facilities.

Nowadays, a considerable amount of greenhouse gas emissions comes from the energy used in buildings, unveiling the importance of finding strategies to produce more efficient buildings. Thus, when creating or refurbishing a building the integration between the design development and energy analysis is very important.

The main objective of this report is to present a methodology for energy management in transport stations using BIM and BEM methodology. This methodology is developed with the intent to comprise the entire process of energy retrofitting, providing an accurate and efficient decision-making process. Through the application of this methodology, it is possible to assess building energy performance in the earliest design phase of a project with a more accurate model, improving the energy efficiency of the existing building. In order to reach a solid methodology, a case study in a real transport station was carried out, applying the developed methodology.

2 DEVELOPMENT OF THE METHODOLOGY

In this topic some concepts are presented along with considerations about the methodology process acquisition. Firstly, a reflection about Building Information Modeling (BIM) and Building Energy Modeling (BEM) is presented. Also some information about the data required to created suitable BIM and BEM models. In a second moment, explanation about the geometric data acquisition, namely point cloud acquisition is presented.

2.1 BIM to BEM

The increasing demand for sustainable buildings, reduction of operation costs and occupant satisfaction has enhanced the energy refurbishment of existing buildings. An efficient energy refurbishment has the potential to reduce the environmental impact of the building and at the same time improve the comfort of the users.

The AEC (architecture, engineering and construction) industry has expressed concern about increasing the energy efficiency and reducing the energy consumption of the buildings. The adoption of methodologies such as BIM and BEM has the potential to contribute for an increased energy efficiency of buildings.

Usually, the energy simulation is performed in the final design phases and separately from BIM. However, the AEC industry is promoting changes in this procedure, by promoting the use of energy studies in the early design phases and in conjunction with BIM. It is documented that the absence of integration between design and energy simulation constrain the suitable energy analysis of the buildings.

An integrated approach between BIM and BEM fills the existent gap, providing more effective and less redundant energy analysis.

The connection between BIM and BEM is provided through common exchange file extensions such as Industry Foundation Classes (IFC) and Green Building Extensible Markup Language (gbXML).

BIM has the capability to integrate data, such as: building geometry, construction geometry and thermal properties, providing accurate virtual models. This methodology is capable to provide a comprehensive digital model, to assist the decision-making process through the entire lifecycle of the building.

Regarding BEM methodology, this is used to perform detailed analysis of the energy performance of a building, using computer-based simulation software. Through this methodology, it is possible to study different solutions and perform different analysis in order to achieve the best options for the energy retrofitting of the building.

For the creation of the as-built BIM and the corresponding BEM, the first step is to perform data acquisition of the existing building, namely Geometric data and Energy-related data.

Geometric data supports the creation of the as-built 3D model and supports all the relevant information about the building. The technologies used in geometric data acquisition are capable to capture the existing building in detail, providing a more accurate BIM model. Laser scanning, photogrammetry, 3D camera ranging, topographic methods and videogrammetry are some of the technologies used in this process.

Energy-related data provides information about the actual conditions of the construction such as the thermal characteristics of the building envelope. There are numerous methods to achieve the energy performance of the buildings, however thermography has been one of the most used methods in recent years. Being pointed out the successful applicability of this method in simultaneous use with laser scanner and/or photogrammetry.

Through the acquired knowledge and the use of a test model, it was possible to develop the first part of the methodology, focusing on data acquisition, building modeling, interoperability and energy analysis.

Regarding the LOD-determination, this was accomplished through the study and survey of energy parameters required for a detailed energy analysis and by studying the LOD tables provided by BIMForum. With all this information and considering the reality of an existing Transport Station, it was possible to point out that LOD 300 is the most accurate to be used in most of the parameters regarding energy analysis. In a retrofitting scenario, it is understandable that most of the energy studies that are carried out pursue new and better energetic solutions to be implemented. Thus, the level of information in these studies must be more detailed than in other scenarios.

The interoperability studies were very useful to understand how the communication between applications is accomplished and how time consuming it is to achieve a correct definition of the models in both BIM and BEM software. In the development of the models for energy analysis some of the parameters must be manually inserted in the energy software, it was detected that there was a correct communication between applications for the thermal properties of the constructive solutions.

Moreover, working with BIM methodology implies a high level of communication between all the stakeholders, and a considerable amount of this assertive communication is achieved through a proper modeling of the building with the right definition of information. Consequently, the correct LOD definition for energy modeling in existing buildings, in this case Transport Stations, will promote a more effective energy analysis, saving time and efforts in the next works.

2.2 Point cloud acquisition

The refurbishment of existing facilities can benefit from techniques that are able to produce accurate and detailed information concerning them. In this section, essential information to develop the methodology for the acquisition of the geometric data is exposed. The laser scanning technology can supply the means to acquire the geometric information required by a BIM model to be used in building energy simulation. In order to better define the technological requirements, extensive studies were conducted on the laser scanning overall requirements and capabilities, researching which parameters improve the ability of the acquired point cloud to serve as a drawing reference during the modeling process.

A laser scanner device emits a laser beam while rotating 360º around the vertical axis. Simultaneously, the mirrored surface from which the laser departs also rotates constantly with respect to an axis perpendicular to the previous one. The emitted laser will reach varied surfaces. Whenever this happens the laser returns to the device with a given energy, which is strong enough to be detected by a sensor. The equipment provides the distances to visible surfaces from where the sensor is located. These same measurements for each point have precisions of the order of centimeters or even millimeters, depending on several factors. Among these factors are the sensor in question, the laser ranges and the surface on which it is incident. In addition to this, other information is measured in order to obtain tri-dimensional points. An example of this is the measurement of the angle of rotation in the horizontal plane of the equipment itself, in relation to the point in question, as well as the measurement of the angle of rotation in the vertical plane of the mirrored surface. This information is subsequently converted into a set of points with a given reference (x, y, z), which are called point clouds. These points may even contain RGB information, which gives color to each point when scanning is accompanied by photographic procedures.

The several laboratory tests were performed, focusing on the laser scanner parameters and its influence over the laser scanner operation and the model LOD. These tests consisted on the acquisition of several point clouds, all taken in the same exact location, under similar conditions, but under different pre-established scanning parameters, which are described in **Erro! A origem da referência não foi encontrada.**.

Table 1 – Scan Stations parameters

Parameter	Description
Resolution	Dictates the distance (in millimeters) between captured points, both vertically and horizontally, for a radius of 10 meters measured from the laser scanner position. The larger the distance, the lower the accuracy and the number of points captured.
Quality	Relates to the precision with which a given point is acquired. Greater quality translates a lengthier scan rotation time, meaning the points are steadily acquired.
White Balance	Allows the acquisition of white tones and the overall photograph color correction. It displays four presets: Sunny; Cloudy; Cold Light; and Warm Light. The first two are used when predominantly subject to natural light, while the last two are used for artificial light.
Image Resolution	Defines the number of pixels, both vertically and horizontally, for the acquired photographs. Higher resolution translates into an higher overall image quality, with fewer blur, but also greatly increases the scan duration and file size.
High Dynamic Range (HDR)	Used to acquire, in higher detail, zones with much/few lights. Photographs are taken with different shutter speeds, obtaining different levels of brightness based on the amount of light that got through the lens. The photographs are then combined resulting into a final photograph with on both the highlight and shadow zones.

Various parameters highly influence the laser scanning operations in terms of scan time and resulting file size. From the tests, it was concluded that a growing scan resolution and image resolution implied a growing estimated time and data file size. It was also possible to conclude that although the scan quality does increase the estimated scan time substantially, the same is not always true for the file size. Furthermore, it could also be concluded that using HDR increases the scan time substantially but the increment on file size depends on the lighting of the scanned area. Moreover, it could be determined that although both scan and image resolution influence the file size and the scan estimated time, the former has a greater influence on these variables than the latter.

In summary, throughout the performed test was possible to conclude that:

- Higher scan quality substantially increases the scanning time;
- Higher scan quality affects the final file size;
- Using HDR substantially increases the scanning time;
- Using HDR slightly affects the final file size depending on the room lighting;
- Image resolution substantially increases both the scan duration and the final file size;
- Scan resolution may extensively increase both the scan duration and the final file size.

In the case of the laser scanner, to determine the parameters that influence on the final model LOD is the same as detecting which parameters alter the point cloud precision and ability to be used as a drawing reference in the modulation process on BIM authoring software.

From the start, it was almost possible to exclude white balance, image resolution, and HDR as impactful parameters because these parameters focus mostly on the esthetic value of the point cloud. Through the multiple tests, it was concluded that only in very specific cases the changes in these parameters allowed for a better modulation process. These cases mostly regarded situations in which the color of the point cloud might give extra information, such as discerning small-distant details such as ventilation grilles.

In what regards scan resolution and quality, since both directly relate with the points position in the point cloud, the scans acquired from several tests with different quality and resolution were used as a tool to determine the impact of these parameters on the geometrical form of the point cloud. These scans indicated that a modification in quality does not result in noticeable differences regarding the point cloud ability to serve as a drawing reference in the modulation process. The scan resolution parameter was a major factor on the final point cloud ability to properly convey the building geometric form.

In summary, was possible conclude that:

- White balance, image resolution and HDR do not affect the quality of the point cloud’s geometrical information. However, on specific occasions, the visualization of the colors of the real building on the point cloud may help discern certain details;
- Scan quality does not visibly affect the quality of the point cloud’s geometrical information;
- Scan resolution has a major impact on the final geometric information conveyed by the point.

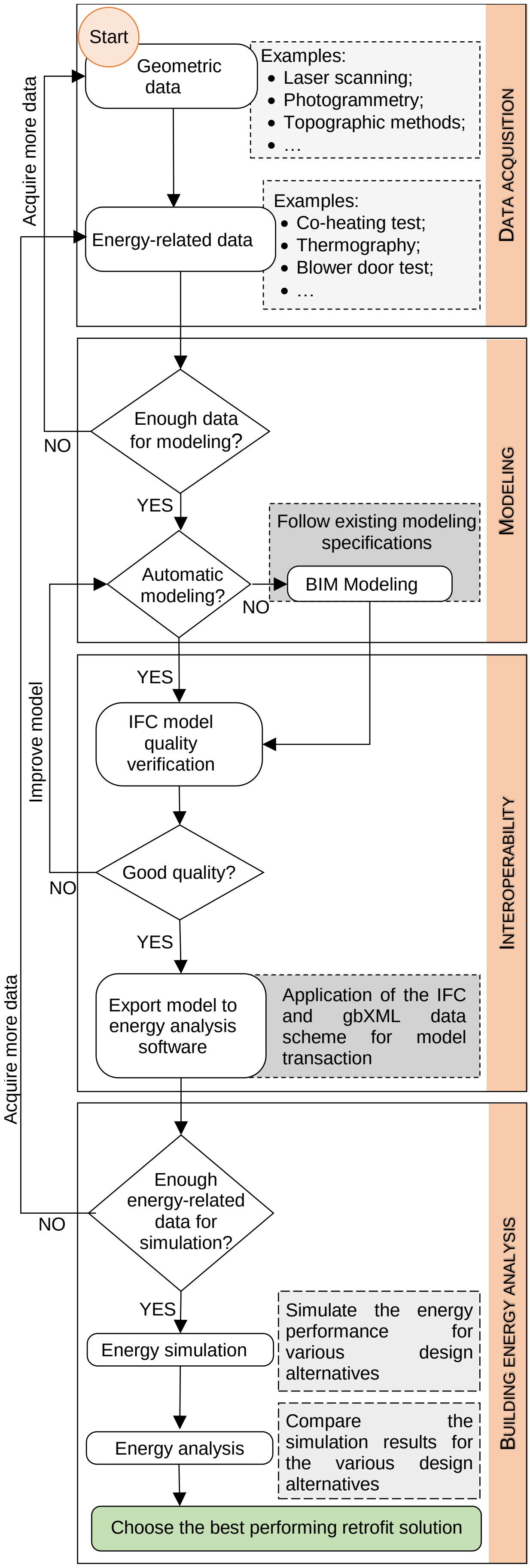
3 METHODOLOGY FOR ENERGY RETROFITING

Alongside the methodology presented in Figure 1 and Figure 2, some guidelines are presented with the intent to assist its interpretation.

The first part of the methodology, Figure 1, presents the BIM approach for energy retrofitting. It comprises four phases, namely data acquisition, modeling, interoperability and building energy analysis.

The second part of the methodology, illustrated in Figure 2, was developed to acquire point clouds that facilitate the modeling process of buildings. This methodology is divided into three main phases: planning, surveying and data analysis.

BIM APPROACH FOR ENERGY RETROFITTING



DATA ACQUISITION

In this methodology the first step corresponds to data acquisition incorporating the Geometric data and Energy-related data. For data acquisition, the user has at his disposal a set of methods and shall choose the best fitting. Regarding the geometric data acquisition, this is explained with more detail in the second part of the methodology.

MODELING

After conclusion of data acquisition and all the required information, it is time to perform the building modeling. For this task it is possible to use automatic or manual modeling, in both cases it is used a BIM authoring software (Revit, ArchiCAD, Sketchup, OpenStudio) to perform the building modeling. This model must contain parameters such as building orientation, dimensions/geometry, building envelope, building type/function, systems and nearby constructions. The building model must comply with BIM standards, using for that the existing specifications such as the Level of Development (LOD) and the Common BIM Requirements (COBIM).

INTEROPERABILITY

Previously to the export of the BIM model to the energy software it is important to ensure the quality of the model to prevent problems of interoperability. If this condition is not accomplished it is necessary to correct the model in the BIM authoring software.

The IFC model quality verification is checked through rule based checking systems such as Solibri Model Checker, Jotne EDModelChecker and FORNAX.

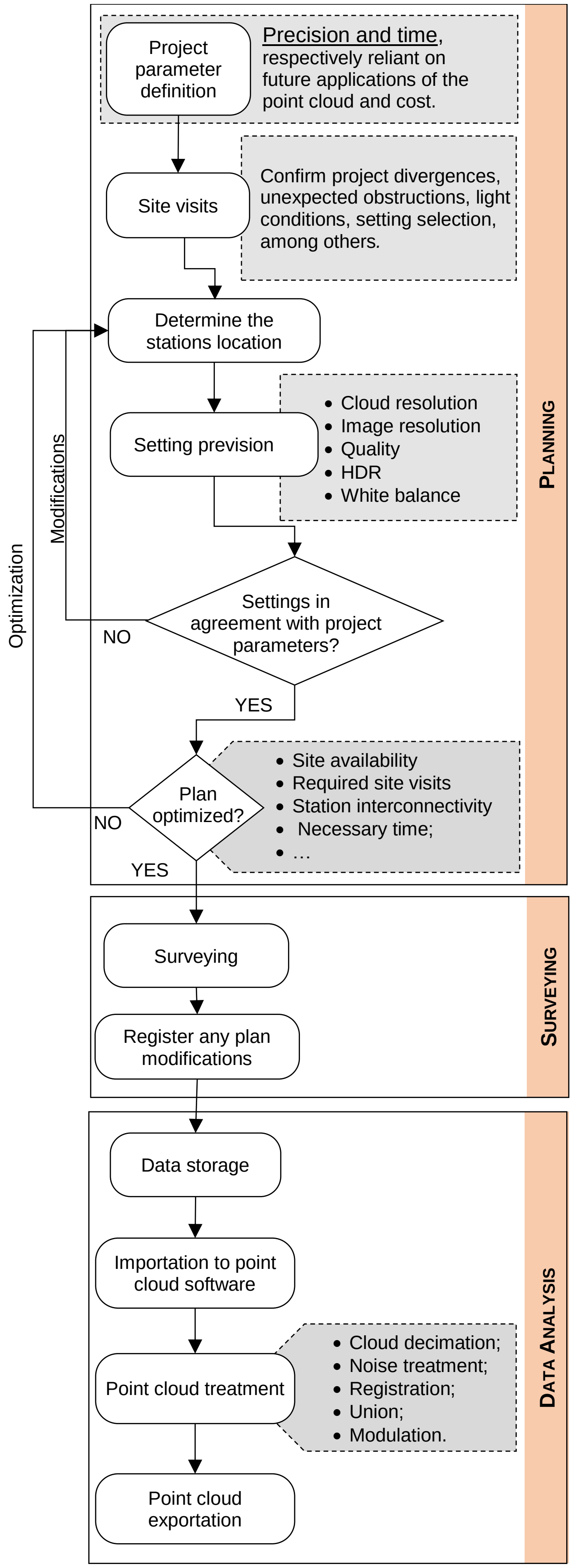
If the energy model complies with the requirements, it is able to be exported. The energy model shall be exported through exchange file extension such as Industry Foundation Classes (IFC) or Green Building Extensible Markup Language (gbXML). The IFC and gbXML data schemes are the mean of transfer information between BIM authoring software and energy analysis software.

BUILDING ENERGY ANALYSIS

In this section, it is necessary to confirm if the energy information is enough. The correct simulation of the existing building will only be successfully accomplished with a detailed model of the real conditions of the building. Ensuring this level of detail it is possible to simulate the energy performance of different designs and systems solutions. Through the collected results, it is possible to compare the different alternatives and choose the best retrofit solutions.

Figure 1 – Methodology for energy retrofitting – BIM approach (adapted from [1]*)*

GEOMETRIC DATA ACQUISITION



PLANNING

In this phase an overall planning of the survey is prepared, allowing for the understanding of the as-is building. The first step is to define the project parameters, namely the precision and available time are determined. The required precision is mostly dependent on the future applications of the point cloud, while the available time may be reliant on several aspects, for example the site schedule and cost restrictions. In the next step, site visits are conducted with different purposes, such as: obtain the survey approval and site plans; checking/confirming project divergences; determining the type of materials and lighting conditions; studying possible scan obstructions and determining the required scanning stations and study their initial settings and location. This information allows delineating the stations interconnectivity and the average necessary time. The accordance between the selected settings and the settings required for the point cloud usage should be confirmed. The number of required stations may be reduced through optimization studies, allowing better interconnections between stations and reducing the survey time.

SURVEYING

In the surveying phase, following the plan idealized in the previous phase, using the selected settings, with modifications or additional information being properly registered.

DATA ANALYSIS

In the final phase, the acquired point clouds are transferred from the laser scanner to a computer station and consequently imported into the point cloud software. In the software the registration (process of unifying the various scans through the identification of at least three concurrent points between scans) and cleaning (process of deleting unwanted data from the scans) of the acquired point clouds is performed. In the last step, the acquired point cloud is imported into modeling software, in order to validate the point cloud usage as a geometric data source for the creation of BIM models.

Figure 2 – Methodology for energy retrofitting – geometric data acquisition

4 METHODOLOGY VALIDATION

In this section is presented the case study of the bus station “Campo 24 de Agosto”, in Porto, Portugal, which was used to validate the proposed methodology, Table 2.

Table 2 – Methodology validation

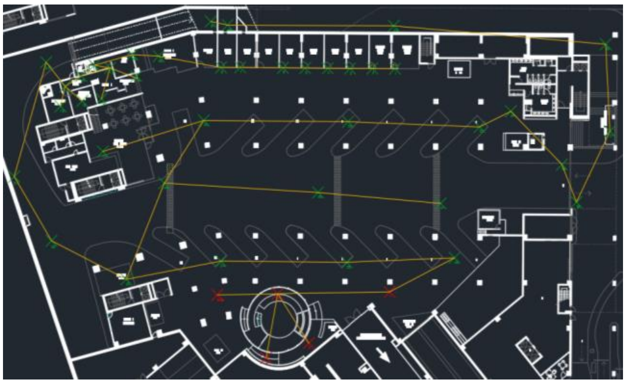
METHODOLOGY FOR ENERGY RETROFITTING

PLANNING AND SURVEYING

Laser scanner (ex: Leica Scan Station P20):


- Selection of the laser scanning to perform the geometric data acquisition;
- Definition of the project parameters: precision and time.

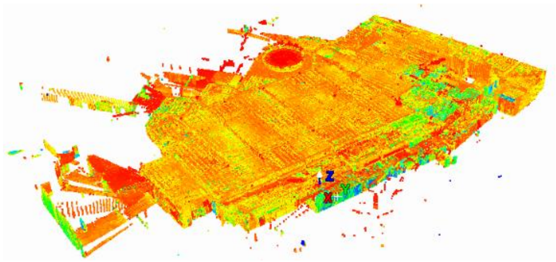
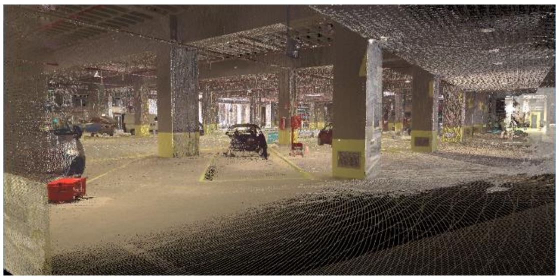
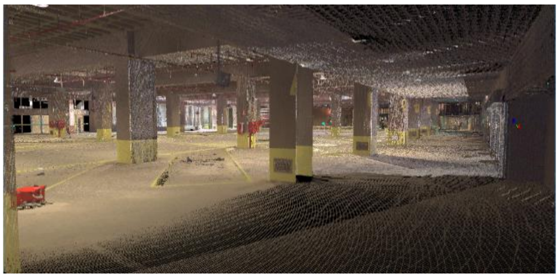
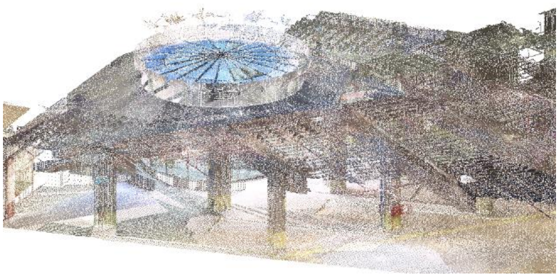
Plan of the scanning stations:

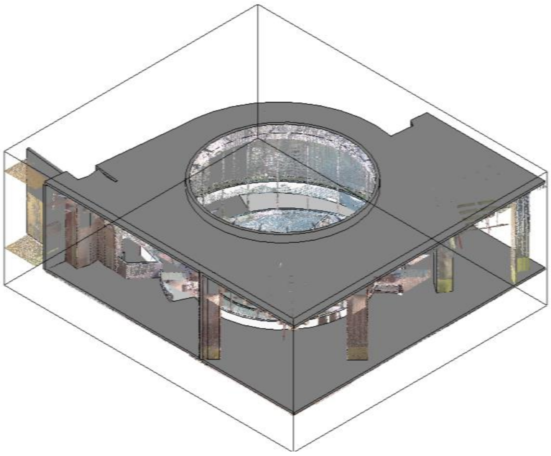
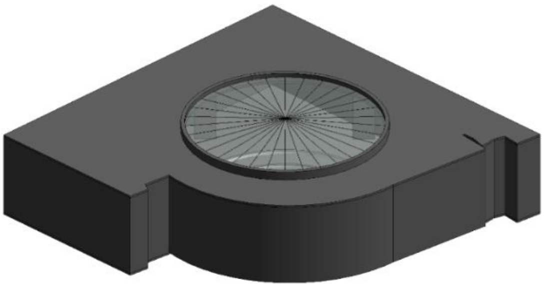
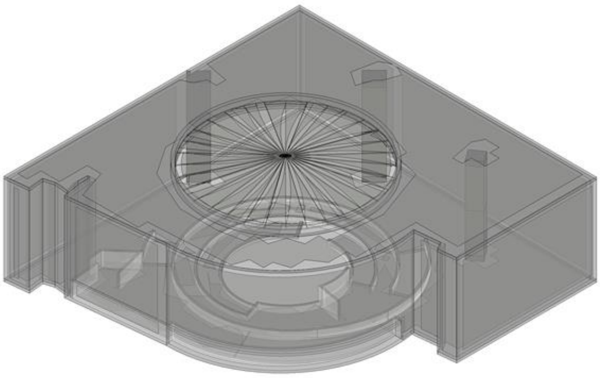
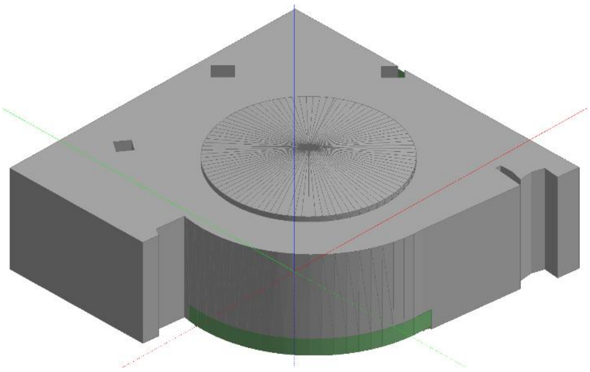


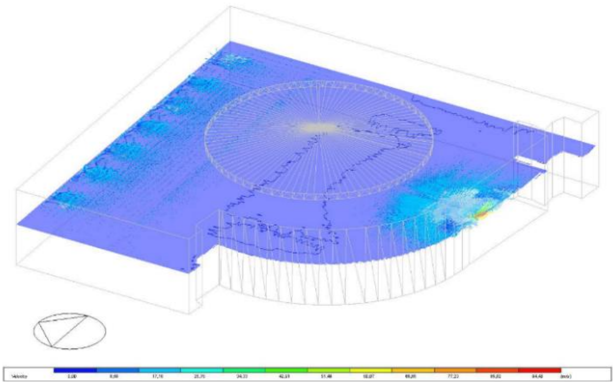
Initial settings:

Scans	Resolution	Quality	White Balance	HDR
1 - 3	6.3	3	cold light	Yes
4 - 7	6.3	3	cold light	No
8	6.3	3	warm light	No
9	12.5	3	cold light	No
10	6.3	3	cold light	No
11 - 12	12.5	3	cold light	Yes
13	6.3	3	cold light	No
14	12.5	3	cold light	No

- Site visits and building plan acquisition;
- Definition of the location of the scanning stations in the plan (54 scan stations);
- Establishing the initial settings of the scans: resolution, quality, white balance, HDR;
- Scanning the building.

DATA ANALYSIS		
	Point cloud (exterior view):  Point cloud treatment:   Point cloud into BIM authoring software: 	• Transfer the point clouds from the laser scanner to a computer station and consequently import into the point cloud software; • Point cloud treatment; • Import the point cloud into BIM authoring software.

MODELING	BIM model creation:  	• Creation of the BIM model from the point cloud in BIM authoring software (ex: Revit). Modeling of floors, walls, roofs, stairs, columns, skylights and windows.
INTEROPERABILITY	Energy Model in the BIM authoring software.  BIM model in the energy analysis software: 	• Verification of the IFC model quality; • Export the energy model to the energy analysis software (ex: DesignBuilder) through the exchange file extension as gbXML.

BUILDING ENERGY ANALYSIS	Energy simulation: 	• Confirm whether the energy information is adequate; • Perform the energy simulation of the existing building; • Analyze the energy results and adopt the best retrofit solution.

5 CONCLUSIONS

This report presents a methodology for energy retrofitting using BIM. This methodology allows for an accurate decision making process, to identify the most adequate solutions to apply in energy retrofitting projects, including the entire process from data acquisition, energy modeling, software interoperability and building energy analysis. With the application of this methodology, the benefits of assessing the building energy performance on a virtual environment may be gathered in the earliest project stages.

The proposed geometric data acquisition methodology allows for an efficient and precise acquisition of as-is geometric data used for building simulation. With the developed BIM methodology, the process to obtain the energy retrofitting project is facilitated and becomes more efficient, leading to better solutions.

An energy analysis of a bus station was successfully concluded with the application of the proposed methodology, through the acquisition and treatment of the geometric data, energy modeling process and software interoperability.

6 REFERENCES

[1] L. Sanhudo *et al.*, “Building information modeling for energy retrofitting – A review,” *Renew. Sustain. Energy Rev.*, vol. 89, pp. 249–260, Jun. 2018.