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Automatic generation of as-is BEM models of buildings

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ABSTRACT

This paper shows a method with which to create a proprietary as-is 3D semantic thermal model of a building and transform it into standard BEM formats. Geometric and relational information regarding the essential structural elements of the building (i.e., zone, ceiling, floor, wall, door, etc.) is, together with their corresponding as-is temperatures, first extracted from thermal points clouds of the scene and then adapted to the standard geometric BEM requirements. Non-geometric properties concerning definitions and properties of envelopes, windows and doors are also defined as essential information. After all this information has been collected, a BEM file is eventually generated in order to be used in energy simulation software. One of the specific features of this work is the generation of as-is BIM formats of the interior of a building that are later adapted for energy simulation applications in EnergyPlus and TRNSYS software. An ASCII file containing the temperatures of the main structural elements of the building is also created. The method has been tested on real thermal point clouds of the ground floor of a building, yielding promising results.

1. Interoperability between as-BIM and BEM: an unsolved problem

Building information modelling (BIM) technology has signified a breakthrough in the Architecture, Engineering & Construction (AEC) field in the last few years, providing geometric and semantic information throughout the life cycle of buildings ([1]). Information of different types can be extracted from the BIM digital model, generating a framework and a database for decision-making of, among other things, an economic, planning or energy efficiency nature ([2]).

One of the applications of BIM is its connection with building energy modelling (BEM), which has been used to improve the energy performance of buildings ([3]). Rather than BIM to BEM this article focuses on existing building to BEM or laser scanning to BEM. From here on we will refer this problem as-is BIM to BEM, in which the term “as-is BIM model” signifies the model obtained after processing the data provided by our thermal scanner system. Since this document focuses on the energy aspect of buildings, in a first phase, the integration of as-is BIMs with BEMs is analysed. The objective of this as-is BIM-BEM integration is to facilitate the evaluation and reduce the amount of rework during the energy simulation of the building ([4]).

Many researchers have proved that complete interoperability between as-is BIM and BEM tools in the AEC field has not yet been totally achieved ([4]). In 2013, Shafiq et al. ([5]) had already shown many of the limitations that still exist today as regards working with standardised BIM formats and the exchange of information between multidisciplinary teams, along with the need to define many of the architectural elements. In current literature, data and information losses or inconsistencies in the geometrical transformations

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continue to be issues as regards the data exchange between as-is BIM/BIMs and BEMs tools ([4,6,7]). This lack of mono or bidirectional interoperability between as-is BIM and BEM means that energy performance study projects for buildings may be inefficient and inaccurate. As the integration of BEM into the BIM workflow has some limitations, energy efficiency strategies are often not well implemented or require a significant amount of time, additional assumptions and remodelling.

The most basic input parameter in the transition from as-is BIM to BEM is geometry, which must be properly adapted. This transition can be accomplished in two ways using a native model defined by the user, that we will call "proprietary model". Both strategies have been developed in this paper. The first option is conducted by passing through an intermediate BIM format. Although the transition from the proprietary model to a standard as-is BIM model can be immediate by transferring the data structures of the primitives to a certain code of a specific format, the adaptation to a BEM model has certain geometric requirements that must be fulfilled. In order to use tools in the BEM environment, they must, therefore, support all the attributes provided by the BIM files [8]. A second option is the use of programming with the objective of converting the native (or proprietary) 3D model into a format supported by an energy simulation tool without going through intermediate BIM formats. This paper also tackles the aforementioned strategy, in which the proprietary model is first generated and then automatically modified in order to make it interoperable with standard energy simulation tools.

2. Generation of as is BIM/BEM from proprietary as-is models

2.1. Previous works

The digitalisation of buildings has recently become the input for the generation of as-is models of buildings. Digitalisation is essentially a technique that provides unobtrusive and raw information on the geometry of constructions. The technologies used in digitalisation are principally 3D scanners, photogrammetry, and RGB-D cameras ([9–11]). Medium or long-range 3D scanners calculate 3D coordinates by bouncing a laser beam that hits the surface of objects, while photogrammetric techniques use images and triangulation techniques to obtain point clouds. RGB-D cameras are, meanwhile, used indoors in order to digitise objects at short distances and use SLAM (Simultaneous Localization and Mapping) algorithms ([12]). In summary, the information acquired by the sensors usually consists of sets of point clouds of visible space with a colour value associated with each point.

The process involved in converting an omnidirectional cloud into a semantic proprietary model of a scene is long, and in the case of being an automatic process, requires a multitude of algorithms concerning principally segmentation and shape recognition/classification ([13]). When the model is obtained by means of a manual procedure, the point cloud serves as a guide to enable an operator to draw the geometry superimposed on the cloud using one of the existing graphic/modelling applications. One of the most significant and pioneering researchers related to the automatic extraction of 3D models is that of Xiong et al. ([14]), in which the essential elements of a construction such as the roof, floor, walls, doors and windows are detected using algorithms based on a response to learning techniques. It is noteworthy that this technique can efficiently deal with disordered environments and with occlusions. Later techniques have achieved the extraction of more representative architectural elements such as columns ([15]), or permanent elements on the walls such as alarms or fire extinguishers ([16,17]). Finally, the objective of other authors has been to detect non-permanent elements, usually furniture, in the scene ([18,19]). Many of these proposals generate data structures that can be called "proprietary models".

There is little research on the transformation of proprietary models into standard models that can be imported by commercial software into BIM or BEM environments. The interoperability and the characteristics of the formats, both proprietary and open for use in the software used in the AEC industry by technicians, is one of the most frequently discussed topics in automatic and semi-automatic generation of as-is BIM models. The loss of information between the agents involved in working with the same information models in different phases of a project is also an issue that has yet to be resolved in many cases and that depends largely on the workflow chosen. Barbini et al. ([20]) carry out a comparison of the interoperability of the standard BIM formats commonly used in the AEC industry and IFC (Industry Foundation Classes), establishing standard labels and parameters that are usually required by different European institutions that use BIM. The results of this research show that when importing IFC to different commercial software, the software makes changes or does not correctly read some labels of the standard format, thus producing errors such as the duplication or triplication of certain characteristics or element parameters, geometry errors or positioning in the scene. As one of the results of the study, the aforementioned authors propose the use of a library of BIM architectural components that are optimised for their use with both open formats (i.e., IFC) and other standard formats.

Of the existing publications on this subject of the transformation of proprietary models into standard models, it is possible to highlight that of Macher et al. ([21]), in which a semi-automatic procedure for the creation of a 3D geometric model in native OBJ format is presented. This contains 3D coordinates (polygonal lines and points), which are eventually converted into an IFC file. Another is that of Barazzeti et al. ([22]), who present a semi-automatic procedure that deals with buildings with complex geometries, and which is particularly focused on the reconstruction of historical and heritage building models on the basis of NURBS (Non-Uniform Rational Basis Splines). The procedure provides a formatted BIM.RTE file. Ham and Golpalvar-Fard ([23]) carry out a test in a residential-type building and generate a GBXML file with transmittance values inserted. The scope of action of this work is a single room. An automatic method with which to convert unstructured point clouds and classify their elements (wall, ceilings, floors) in order to generate a 2D plan in CAD format and a 3D BIM model in an automatically generated IFC format is, meanwhile, proposed by Gankhuyag and Han [24]. However, it is clear neither what type of information, apart from the geometric information, is incorporated, nor what its interoperability is.

2.2. Contributions of the paper

Given the lack of research on the issue of creating BEM models in standard formats, the main contribution of this publication is to develop a methodology that addresses this problem. This paper proposes a methodology that first creates an as-is 3D thermal proprietary model of the interiors of buildings and then automatically transforms the proprietary model into a standard BEM model. This contribution can be synthesized in the following points.

I. The creation of 3D thermal proprietary models of different zones {TPM(Z_1), TPM(Z_2),… TPM(Z_n)} of the building, in which a zone is an open space or a room. This is an innovative aspect that should be highlighted with respect to the aforementioned proprietary models, which provide no information concerning the temperature.
II. The integration of the set {TPM(Z_1), TPM(Z_2),… TPM(Z_n)} into a common reference coordinate system and the generation of a unique model of the scenario (TPM) that satisfies the geometric requirements of a standard BEM model.
III. The exportation of TPM to two energy file formats denominated as a *PreBEM_1* and *PreBEM_2* files, and the importation of them to two standard BEM software.

The most important aspects of the aforementioned contributions are presented in the following sections. Section 3 deals with the methodology as regards the creation of the thermal proprietary model, which is divided into several phases: the creation of omnidirectional thermal clouds; point cloud segmentation into essential structural elements (SEs) of the building; the definition of the geometry of the SEs, and the zone coupling process. Finally, the 3D model containing geometric and thermal properties is defined and the TPM database is described. Section 4 focuses on the creation of BEM models. The adaptation of TPM to the basic geometric requirements of standard BEM models is covered in subsection 4.1., whereas the generation of *PreBEM* files and their integration into BEM software are addressed in subsection 4.2. As an experimental demonstration, a case study of a one-storey building with several zones is presented in Section 5, in which the automatic generation of *PreBEM_1* and *PreBEM_2* files and their importation to EnergyPlus and TRNSYS software respectively is also shown. Section 6 is devoted to showing several applications of the method in which the temperature information is used. Finally, the conclusions of the work are presented in Section 7.

3. Creation of a 3D thermal proprietary model

From here on, it is assumed that the objective is to perform a thermal digitisation of an interior space, which can be composed of several rooms (or zones) interconnected by their corresponding doors. It is also assumed that there may be columns, pilasters, doors and windows in the scene. In addition, the sensory system that thermically digitises the scene consists of a medium-range 3D scanner, an HD Colour camera and a thermal camera.

The general outline of the generation of a 3D thermal proprietary model is represented in Fig. 1, in which we distinguish between the initial phases (1 and 2), the data processing phase (3) and the creation of a semantic model phase (4 and 5). Since this paper is focused principally on how to use the proprietary model in order for it to be transferred to the BEM environment, and not on describing how it is generated, the following paragraphs will briefly present the fundamental steps of this process. For more information, please consult references [25–28].

3.1. Scanning planning

In the data collection planning phase, the scenario to be scanned, its dimensions, the necessary positions, and orientations of the sensory system required in order to capture the largest possible space and the appropriate degree of sensory resolution are studied. The use of additional temperature and humidity sensors for exterior and interior spaces, along with contact temperature sensors, which act as the ground truth of the temperatures provided by the infrared camera, are also evaluated.

Furthermore, in order to make corrections to the temperature provided by the thermal camera (which must be forced to set the emissivity to 1), small targets made of aluminium foil and insulating tape are placed on the walls. The measurement of the apparent temperature provided by the camera is subsequently corrected on the basis of the temperatures obtained in these targets.

3.2. Data acquisition

In the data acquisition phase, the following information is stored for each scan: the XYZ coordinates provided by the sensor, a set of RGB images and a set of IR images.

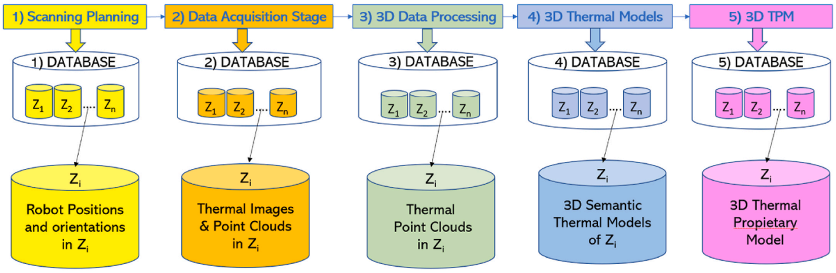


Fig. 1. General outline of the creation of a 3D thermal proprietary model.

The scanner usually records data with field of view (FoV) in azimuth of 360°, and variable elevation in a range of between 120° and 300°. However, because the cameras (both colour and infrared) used in our sensory system have a reduced FoV, in the case of a 360° turn of the scanner, only a strip of superimposed images of a certain angular amplitude can be obtained, usually less than 70°. This circumstance makes it necessary to use several cameras that cover the entire vertical range (which is the case of the three colour cameras) or to tilt the sensory system in the elevation angle (which is the case of the single thermal camera) with at least one negative and one positive angle. This, therefore, allows the set of images to cover the space visible from one position.

The data acquisition phase is completed by moving the sensory system to other positions in the scene, in the same room and in other rooms, repeating the same operation mentioned above. More information and details on the sensorial system can be found in Ref. [25].

3.3. Data processing

The objective of this phase is to generate a set of thermal clouds for each of the zones in the scene, that is, a set of 3D coordinates referred to as a common system, in which each point has an associated apparent temperature.

In order to generate a simple thermal cloud with a scanner and thermal camera system (extensible with an RGB camera), a calibration process is performed beforehand. This provides the correspondence between the 3D coordinates of the points and the pixels of a thermal image. The calibration procedure and the algorithm employed in order to obtain a 360-thermal point cloud were published in Ref. [26]. The alignment of the thermal point clouds obtained from different positions and/or orientations of the set scanner-RGB camera-Thermal (usually referred to as a registration process) is performed manually or with the help of an odometry system and subsequent point-in-space adjustment algorithms ([27]).

The output of this phase is, therefore, a set of thermal (and colour) clouds associated with zones Z_1, Z_2, …Z_n., signifying that this is still unstructured information, and that it is far from being a geometric and thermal model of the scene.

3.4. 3D thermal models of zones

In the thermal model creation phase, the following processes are undertaken sequentially: point cloud segmentation, the creation of geometry for each segment, the assignment of an apparent temperature to each segment and temperature correction. The following subsections show the process followed for each thermal cloud in a zone (typically a room).

(1) The thermal cloud is segmented by: removing outliers, detecting planes adjusted to points, and defining facets. These processes make it possible to segment the points appertaining to the floor, ceiling and walls. See Ref. [29] for more information.
(2) The initial geometry of the facets corresponding to the floor, ceiling and walls, which are from here on considered to be structural elements (SEs), are obtained. The algorithms that detect and delimit doors and windows on the orthoimages of each of the walls are subsequently run, and the 3D coordinates of their facets are also obtained. Detailed information of this stage can be found in Ref. [16] (opening detection) [28], (semantic segmentation of SEs) and [30] (scan-to-BIM for small building components).
(3) Apparent average temperatures for each segment of points corresponding to each wall, door or window are calculated and assigned as the reference temperature in the proprietary model.
(4) The correction of the former average apparent temperatures is carried out after measuring the temperatures of adhesive tape (for which an emissivity of 0.95 is assumed) and aluminium foil targets on each of the thermal orthoimages. These are used to calculate the emissivity of the materials present in the scene, such as: aluminium or PVC (for windows), wood (for doors) or brick or mortar (for walls). Finally, their real temperature is calculated and reassigned.
(5) Creation of the database that stores the earlier data of each zone.

3.5. The 3D thermal proprietary model (TPM)

After aligning the set of 3D thermal models of the zones in a common coordinate system, the whole scenario is represented as a unique data structure denominated as the 3D Thermal Proprietary Model (TPM). An Adjacency Matrix (AM) concerning the structural elements of different zones is also calculated and introduced into the TPM. The components of the TPM are illustrated in Fig. 2.

The main fields of a TPM data structure of a certain *j-th* SE of the *i-th* zone are:

- *PC*: This is the homogeneous point cloud containing RGB and temperature information associated with the *j-th* SE of the *i-th* zone.
- *SE_3D_coord*: this contains the 3D coordinates of the *j-th* facet of the SE.
- *color_image*: this is an RGB orthoimage of the *j-th* SE.
- *depth_image*: this is a z-orthoimage of the *j-th* SE.
- *temp_image*: this is a thermal-orthoimage of the *j-th* SE.
- *door_3D_coord*: this contains the 3D coordinates of the doors (if any) of the *j-th* SE.
- *door_2D_coord*: this contains the 2D image coordinates (in pixels) of the doors (if any) of the *j-th* SE.
- *window_3D_coord*: this contains the 3D coordinates of the windows (if any) of the *j-th* SE.
- *window_2D_coord*: this contains the 2D image coordinates (in pixels) of the windows (if any) of the *j-th* SE.
- *T_Range*: range of temperatures in the *i-th* zone.
- *T_SE*: average temperature of the *j-th* SE.
- *T_door*: average temperature of the doors (if any) of the *j-th* SE.
- *T_window*: average temperature of the windows (if any) of the *j-th* SE.
- *Adjacency*: this is a set of codes of the of the *j-th* adjacent structural elements (if any) of the SE that belong to other zones.

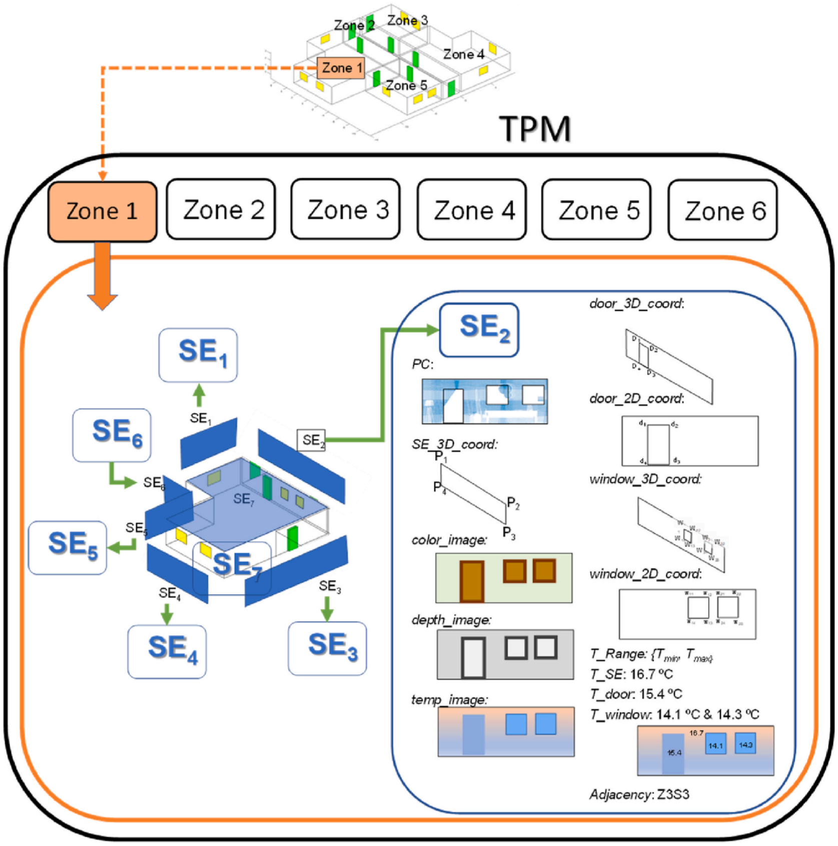


Fig. 2. The 3D thermal proprietary model (TPM).

4. Towards the creation of BEM models

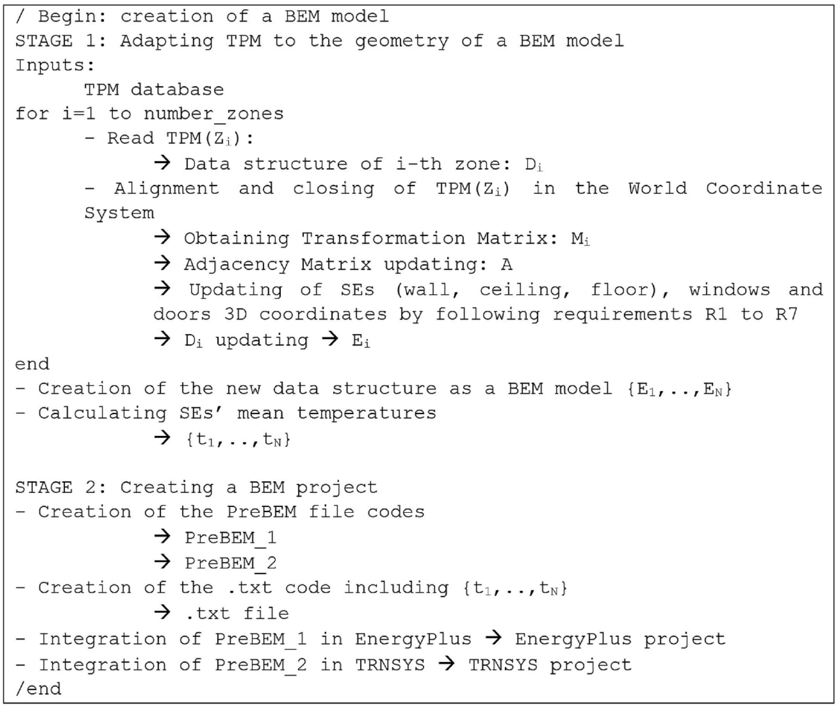
The pseudocode of the algorithm that creates a BEM project using our TPM is represented in Fig. 3. This process basically consists of two stages: first, an adaptation of the TPM to the geometric requirements of a standard BEM, and second, the generation of a basic BEM code (*PreBEM* file) and its integration into BEM software.

4.1. Stage 1. adapting the TPM to basic geometric BEM requirements

Our system performs an automatic conversion from the former 3D proprietary model to a BEM model, primarily by recalculating a few issues concerning aspects of geometry and adjacency. The principal geometric requirements of a BEM model are shown as follows. Graphical details are illustrated in Fig. 4.

R1) The difference between the internal volume and the analytical volume, that is, the space enclosed between the central planes, must be considered.
R2) Closed volume: the entire structure of the scanned space must be closed. This forces all the vertices of the faces to be adjusted, while the vertices of adjacent faces remain the same.
R3) Coplanarity: the door and window elements must be coplanar to the corresponding walls.
R4) Adjacency: during the generation of multi-zone BEM formats (for example, in IDF formats) the adjacent walls must share vertices and the adjacency is defined in both directions. If the same enclosure faces two different spaces, it will have to be divided in order to define the boundary conditions of each of the zones. The part that faces another thermal zone is labelled as adjacent, while that which faces an exterior zone or an interior zone is labelled as exterior.
R5) Concavity: the repercussion of concave areas in the calculation of a BEM file mainly affects glass enclosures that face the outside, resulting in an increase in the demand value of the building. This effect appears in some software (e.g., TRNSYS and Sketchup). Elements with minor concavities owing to pillars and others, do not have a significant effect, although it can be simplified to a straight enclosure if there is an adjacency on that side, and this is simpler.
R6) Ordering of vertices: the ordering of the vertices of all the elements must follow the clockwise direction always seen from within the zone, otherwise there will be inconsistencies in the belonging of these elements to their respective zones.

Apart from the aforementioned geometric requirements, we have also obtained two pieces of non-geometric information that could be useful in energetic software in future developments.



```
/ Begin: creation of a BEM model
STAGE 1: Adapting TPM to the geometry of a BEM model
Inputs:
      TPM database
for i=1 to number_zones
      - Read TPM($Z_i$):
            → Data structure of i-th zone: $D_i$
      - Alignment and closing of TPM($Z_i$) in the World Coordinate
      System
            → Obtaining Transformation Matrix: $M_i$
            → Adjacency Matrix updating: A
            → Updating of SEs (wall, ceiling, floor), windows and
            doors 3D coordinates by following requirements R1 to R7
            → $D_i$ updating → $E_i$
end
- Creation of the new data structure as a BEM model {$E_1$,..,$E_N$}
- Calculating SEs' mean temperatures
            → {$t_1$,..,$t_N$}

STAGE 2: Creating a BEM project
- Creation of the PreBEM file codes
            → PreBEM_1
            → PreBEM_2
- Creation of the .txt code including {$t_1$,..,$t_N$}
            → .txt file
- Integration of PreBEM_1 in EnergyPlus → EnergyPlus project
- Integration of PreBEM_2 in TRNSYS → TRNSYS project
/end
```

Fig. 3. Algorithm for the creation of a BEM project.

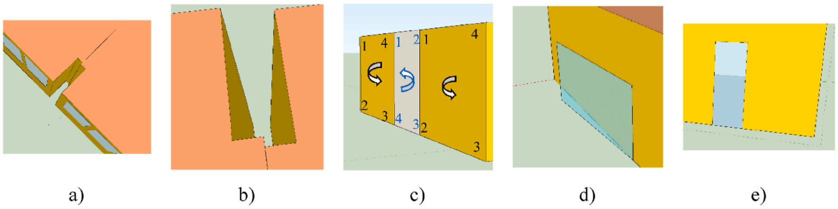


Fig. 4. Problems with the requirements in a BEM model: a) and b) coincidence of points in adjacent space and concavity, c) ordering of vertices, d) coplanarity and e) definition of windows.

- Energy parameters. It is possible to include values of energy parameters such as the Thermal Resistance (or Transmittance) of walls, windows and doors. In our case, the system includes this possibility.
- Temperature information. It is not currently possible to include the temperatures of structural elements (closures, doors and windows) in the codes that are imported by BEM tools. However, these can be modified or calculated within it. One possible solution by which to import temperature information would be the use of a.txt or.xlsx file that contains the corrected temperature for each element in each zone.

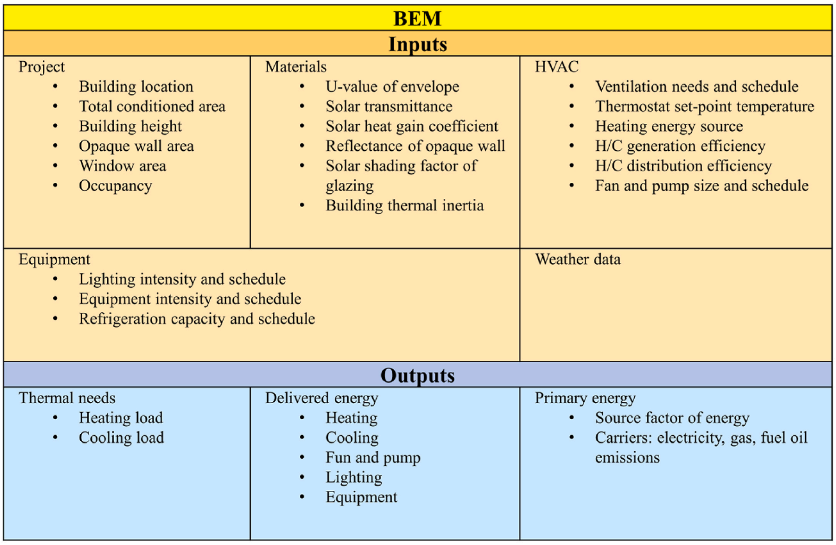
Since the original proprietary model presented in Section 3 does not verify any of the requirements enumerated, the transformation of the TPM into a model containing these geometric specifications is carried out.

4.2. Stage 2. creation of the PreBEM model and its integration into a BEM project

In order to generate a complete standard file that can later be used in energy simulation software, after adapting a TPM to typical BEM geometric requirements (in Subsection 4.1), our system must generate a code with more information than that contained in the geometry, such as building orientation and positioning, types and properties of walls or types and properties of windows.

As mentioned above, different means, methods and formats are being developed in the BEM world. Fig. 5 shows a general state of the art of inputs of a BEM model and some of the main outputs that can be obtained from it. As discussed in Ramaji et al. [31], the existence of this wide range of inputs and formats makes it difficult to match formats and data structures in different BEM formats. In this paper, we aim to automatically generate the input “Project” in Fig. 5, and manually insert some of the remaining inputs of the BEM project.

The proprietary model has been adapted to two initial formats (from here on, called *PreBEM_1* and *PreBEM_2)* following the specifications of section 4.1. Afterwards, *PreBEM_1* and *PreBEM_2* can be used (imported) by the Energy Plus and TRNSYS software respectively. We have chosen the EnergyPlus (EP) and TRNSYS energy simulation software as a good representative set of simulation engines. EnergyPlus is a whole building energy simulation programme used by engineers, architects, and researchers to model both en-



BEM

Inputs

Project
- Building location
- Total conditioned area
- Building height
- Opaque wall area
- Window area
- Occupancy

Materials
- U-value of envelope
- Solar transmittance
- Solar heat gain coefficient
- Reflectance of opaque wall
- Solar shading factor of glazing
- Building thermal inertia

HVAC
- Ventilation needs and schedule
- Thermostat set-point temperature
- Heating energy source
- H/C generation efficiency
- H/C distribution efficiency
- Fan and pump size and schedule

Equipment
- Lighting intensity and schedule
- Equipment intensity and schedule
- Refrigeration capacity and schedule

Weather data

Outputs

Thermal needs
- Heating load
- Cooling load

Delivered energy
- Heating
- Cooling
- Fun and pump
- Lighting
- Equipment

Primary energy
- Source factor of energy
- Carriers: electricity, gas, fuel oil emissions

Fig. 5. Inputs and Outputs in a standard BEM model.

ergy consumption for heating, cooling, ventilation, lighting and plug and process loads, and water use in buildings ([32]). With regard to TRNSYS, it is a transient system simulation programme based on a component approach with a modular structure. Moreover, the TRNSYS library includes a detailed multi-zone building model and components for HVAC systems, renewable energy systems, etc. ([33]).

PreBEM_1 is automatically generated by passing through an intermediate file GBXML (with the specifications of section 4.1) and then imported by Design Builder (which allows us to visualize the 3D model). This software finally generates an IDF file that can be imported by Energy Plus.

PreBEM_2 is automatically generated without passing through an intermediate file. In fact, *PreBEM_2* is a kind of IDF file that is imported by SketchUp (a free program that allows us to visualize the 3D model). SketchUp generates another IDF file that can eventually be imported by TRNSYS.".

*PreBEM_*1 and *PreBEM_2* contain the main items of the "Project" input depicted in Fig. 5. As will be shown in Section 5.4, these files will be successfully imported by EnergyPlus and TRNSYS and then manually completed (if desired) by employing the same software, along with some of other inputs from Fig. 5. As an example, the code of the *PreBEM_2* file specifically contains the following information:

- Building surface. Description of the 3D building model, considering different thermal zones.
- Building orientation and positioning.
- Types and properties of Walls.
- Types and properties of Windows.
- Shading of building. External shadings.
- Essential materials used for the envelopes.
- Schedules.
- Information regarding geometry and properties of objects.

The insertion of *PreBEM_2* (or *PreBEM_1*) into TRNSYS (or EnergyPlus) still requires several steps. First, *PreBEM_2* must be imported by means of TRNBuild (an assistant with which to set up a multi-zone building project in TRNSYS), generating the Type 56. Second, in order to create a TRNSYS project, *PreBEM_2* is added manually, together with files or information concerning the weather (by inserting a weather data file.tm2), the building rotation angle with respect to the North, the solar direct radiation fraction on the floor, the shading control depending on the total radiation on the window and the boundary and ground temperatures. All this information creates the basic TRNSYS model, which is then ready to be used in subsequent energy simulation processes. Other items related to default gains, other gains, comfort, infiltration, ventilation, cooling, heating, etc. can also be included in the TRNSYS project manually by means of TRNBuild.

5. Experimentation carried out using the method

5.1. Case study

The method described in the preceding section has been successfully applied to the interiors of buildings. As a case study, the experimentation and the results obtained in a building floor-type space consisting of 5 interconnected rooms (or zones) are presented. The digitized space corresponds to a floor plan of 13.55 m × 13.80 m, with a total of 186.99 m^2 and a volume of 747.96 m^3. The complete digitisation of this volume required the attainment of 21 thermal scans, and the processing of a total of about 250 million points and 210 thermal images of 160 × 120 pixels, with a FoV of 71° × 56° (v x h). The resolution of thermal orthoimages is 1 datum for every 2 square centimetres.

5.2. The thermal proprietary model: creation of thermal point clouds and zone models

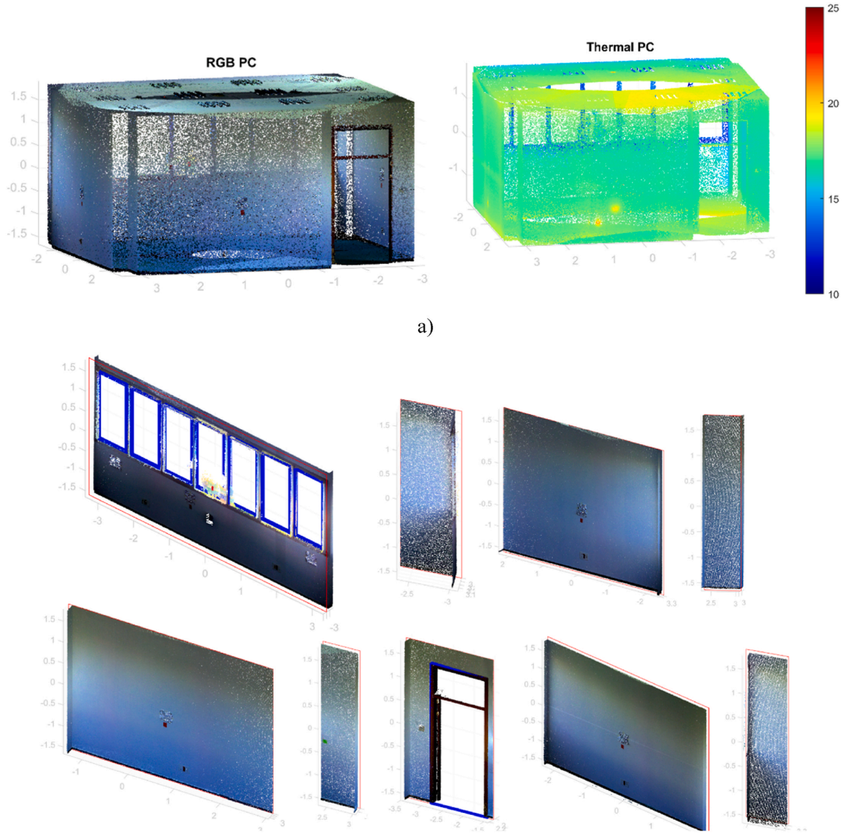
The results of the TPM are illustrated in the following figures. Some of the TPM fields (*PC, SE_3D_coord, colour_image, depth_image, temp_image, door_3D_coord, door_2D_coord, window_3D_coord, window_2D_coord, T_Range, T_SE, T_door, T_window, Adjacency*) described in Section 3.5 are presented for specific zones and structural elements.

Fig. 6 a) shows the RGB and thermal points of zone 4, in which the temperature range of the colour palette has been fixed according to the field *T_Range*. Fig. 6 b) illustrates the segmentation results obtained for zone 4. Note the point cloud assigned to the largest walls in this zone. In this case, the *PC* field has been used. The *colour_image* field employed for the same previous segments is presented in Fig. 7a). In this case, the *door_2D_coord* and *window_2D_coord* fields are used to draw the position of the doors and windows in the image. Fig. 7b) shows the *temp_image* field for the same segments.

The proprietary thermal model of several zones composed of structural elements, windows and doors are superimposed onto the regularised thermal point cloud shown in Fig. 8a). In order to draw this figure, we have used the fields concerning the 3D coordinates *SE_3D_coord, door_3D_coord and window_3D_coord,* along with the corresponding average temperatures *T_SE, T_door* and *T_window*. These temperatures are printed inside the figure. Finally, the TPM models of each zone with the average temperature assigned to each element are presented in Fig. 8b). In this case, the colour code palette of each element is according to its average temperature.

5.3. Geometric adaptation of zones following BEM requirements

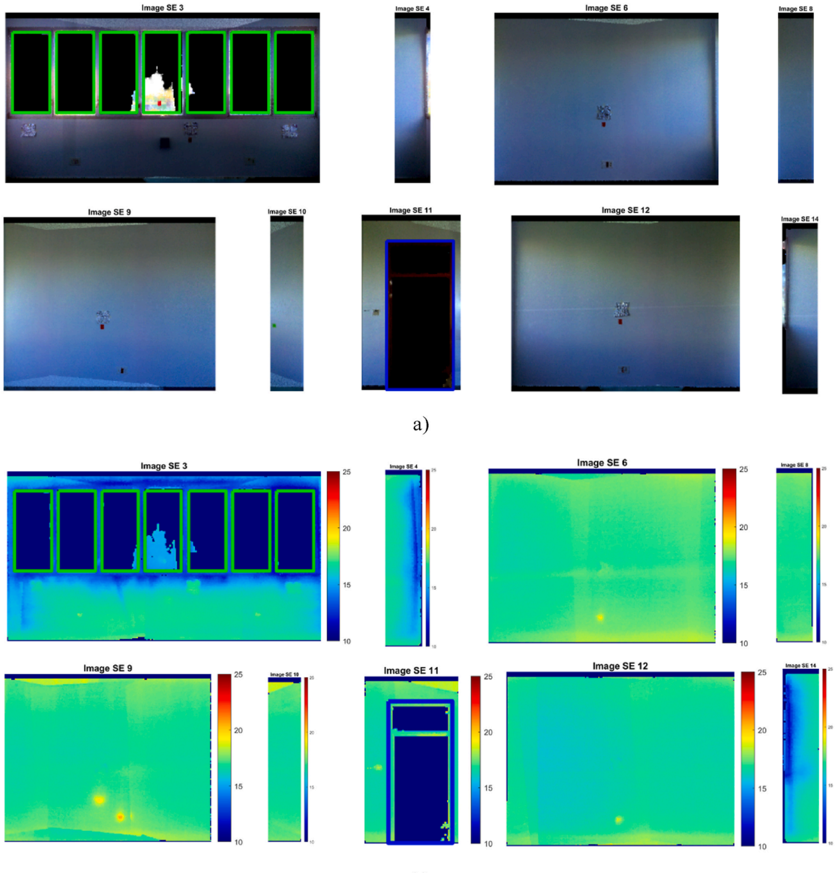
As already explained in Section 4.1, the proprietary model is converted into a 3D model that follows the BEM specifications. The sequence required by the zone coupling and closing algorithm is followed. First, the closure of Zones 0 and 1 is carried out. Next, Zone 2 is coupled to the earlier set and the coupling is repeated for Zones 3 and 4. In this process, in addition to updating the coordinates of the facets that represent the elements of the coupled area, the matrix of adjacencies between walls is updated. The numbering of all the walls, doors and windows is then carried out in a clockwise direction. The final BEM model with average temperatures is presented in Fig. 9 using a proprietary viewer.



a)

b)

Fig. 6. Results for different stages in the creation of a Thermal Proprietary Model and TPM fields. a) RGB and thermal points of zone 4 (*T_Range*). b) 3D Segmentation results in zone 4 (*PC*).



a)

b)

Fig. 7. Results for different stages in the creation of a Thermal Proprietary Model and TPM fields. a) Segmentation results in 2D (*colour_image, door_2D_coord and window_2D_coord*). b) Temperature orthoimages (*temp_image, door_2D_coord and window_2D_coord*). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

5.4. Generation of PreBEM_1 and PreBEM_2 files

Once all the geometric information has been correctly arranged, first the labelling of the elements is assigned, after which the *PreBEM_1* and *PreBEM_2* files are generated according to their respective structure within the text code. The GBXML format (later *PreBEM_1)* requires more geometric parameters than that IDF format imported by SketchUp (later *PreBEM_2*), which requires complementary data, such as the total area, volume, and area of each room. For each surface and opening, it is also necessary to indicate the height, width and, tilt and azimuth angular parameters. All these parameters are automatically calculated from the proprietary model.

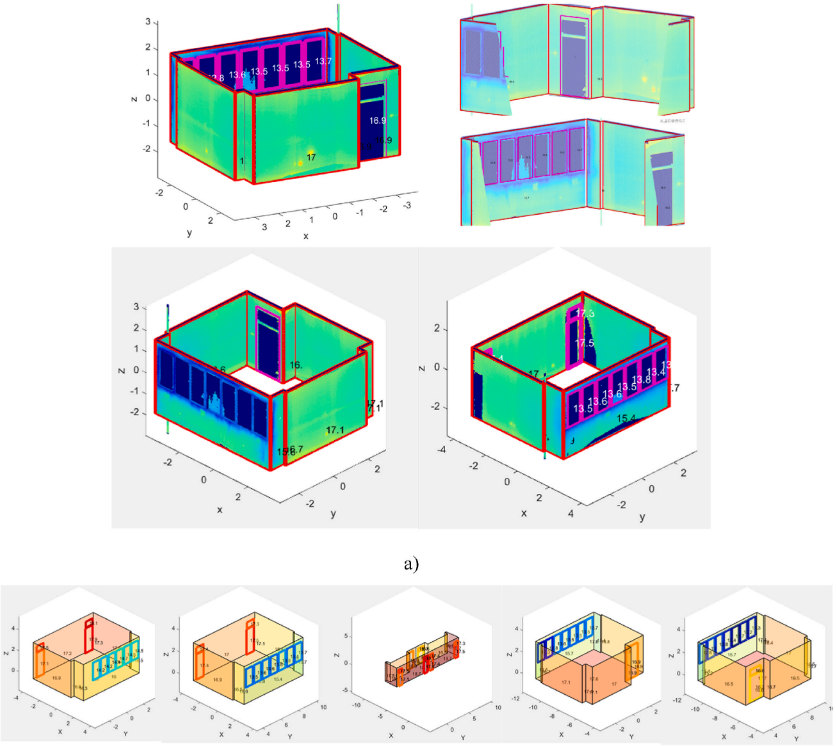
The architectural elements that appear in the IDF/GBXML files generated are structured in 5 zones, with 5 floors (GROUND_FLOOR/UndergroundSlab), 5 external ceilings (EXT_ROOF/Roof), 54 external walls (24 EXT_WALL/ExteriorWall) and 30 internal walls (ADJ_WALL/InteriorWall), 37 windows (EXT_WINDOW1/FixedWindow) and 12 doors (EXT_WINDOW2/NonSlidingDoor).

As an example, Fig. 10 shows the description of the elements obtained in Zones 0 and 1 for an IDF format, with the following nomenclature: Z = zone, S = wall, P = door, V = window. Fig. 11 a) shows a part of the *PreBEM_2* and *PreBEM_1* codes that refers to the geometric data of wall #8 of zone #1.

Several parts of the *PreBEM_2* code that concerns non-geometric information are illustrated in Fig. 11 b). These are layer definition, wall properties, window properties, building location and schedules. As mentioned in Section 4.2, the items Default Gains, Other Gains, Comfort, Infiltration, Ventilation, Cooling and Heating are not included in *PreBEM_2* and, if desired, will have to be manually defined in the TRNSYS project itself.

Fig. 12 presents the text file that provides the real average temperatures of each element of zones #0 and #1. Finally, Fig. 13 shows *PreBEM_1* and *PreBEM_2* files viewed in Design Builder and TRNSYS, respectively.

Fig. 14 shows two shots of the process of integrating *PreBEM_2* into TRNSYS. In Fig. 14a), the *PreBEM_2* file (model.idf in the picture) is inserted into the TRNSYS3d file box in order to create a TRNSYS project. Note that the boxes corresponding to the weather, the building rotation angle, the solar direct radiation fraction on the floor, the shading control depending on the total ra-



a)

b)

Fig. 8. Results for different stages in the creation of a Thermal Proprietary Model and TPM fields. a) Structural elements, windows and doors superimposed onto the regularised thermal point cloud (*PC, SE_3D_coord, door_3D_coord, window_3D_coord, T_SE, T_door and T_window*). b) TPM model of each zone with the average temperatures (*SE_3D_coord, door_3D_coord, window_3D_coord, T_SE, T_door and T_window*).

diation on the window and the boundary and ground temperatures are also filled in. Fig. 14 b) illustrates the scheme of a TRNSYS project. Several inputs have been considered in the thermal balance of our building and several outputs are generated.

6. The use of the temperature and BEM models

We are aware that the applicability of this method is an important issue that researchers and practitioners usually demand. Since this matter has not been properly highlighted in the paper, we present three applications in which we are currently working on.

As stated in the article, the thermal information provided by our method cannot be inserted into a BEM format. However, we are currently using temperature information and BEM models in several applications.

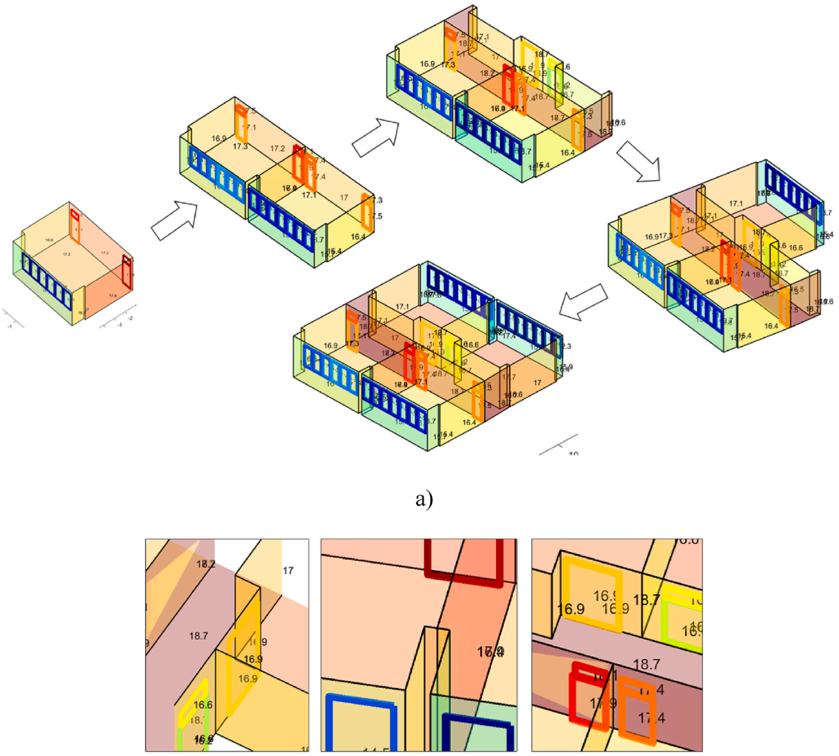
On one hand, the temperature is used for calibration processes in energy simulators. Specifically, the *PreBEM_1* file (which originates from GBXLM) is imported by EnergyPlus and the thermal information is used as input of CFD simulation processes in which the temperatures of the planes near the walls, floors and ceilings are simulated. By means of the variation of initial conditions (HVAC), a convergence is reached between the measured and simulated temperatures, thus performing a calibration of the boundary conditions.

The second utility focuses on visual thermal evaluation of building envelopes over time. The *PreBEM_1* file along with the corresponding thermal information (included into a.txt file) are imported to Unity ([34]). We are developing several applications in augmented reality environments ([35]) in which the user is immersed in a 3D environment, and can explore and analyse temperatures of point clouds at different times.

The third application refers to the use of *PreBEM_2* and the temperature in TRNSYS. Since TRNSYS works in transitory regime, the temperatures collected in our system can be used to validate a model in which external climatic data and the transmittance of the enclosures are known. For this, periods of at least 24 h of data are needed. To determine the transmittance of the enclosure with thermography we need a period of several hours. TRNSYS provides the surface temperatures of the enclosures considering the materials used in the enclosure, and the exterior and interior boundary conditions. The temperature data obtained from the simulation could thus be compared with the data collected with the thermographic camera over a period of sufficient duration. In this application, recommendations and requirements on the experimental methods based on infrared thermography measurements must be followed according to the Normalisation European Committee 1998 ([36]).

7. Conclusions

Although many publications show solutions to the problem of automatically or semi-automatically obtaining a 3D model (which has been denominated as a “proprietary model”) from point clouds, few researchers explain and solve the transition from this propri-


a)

b)

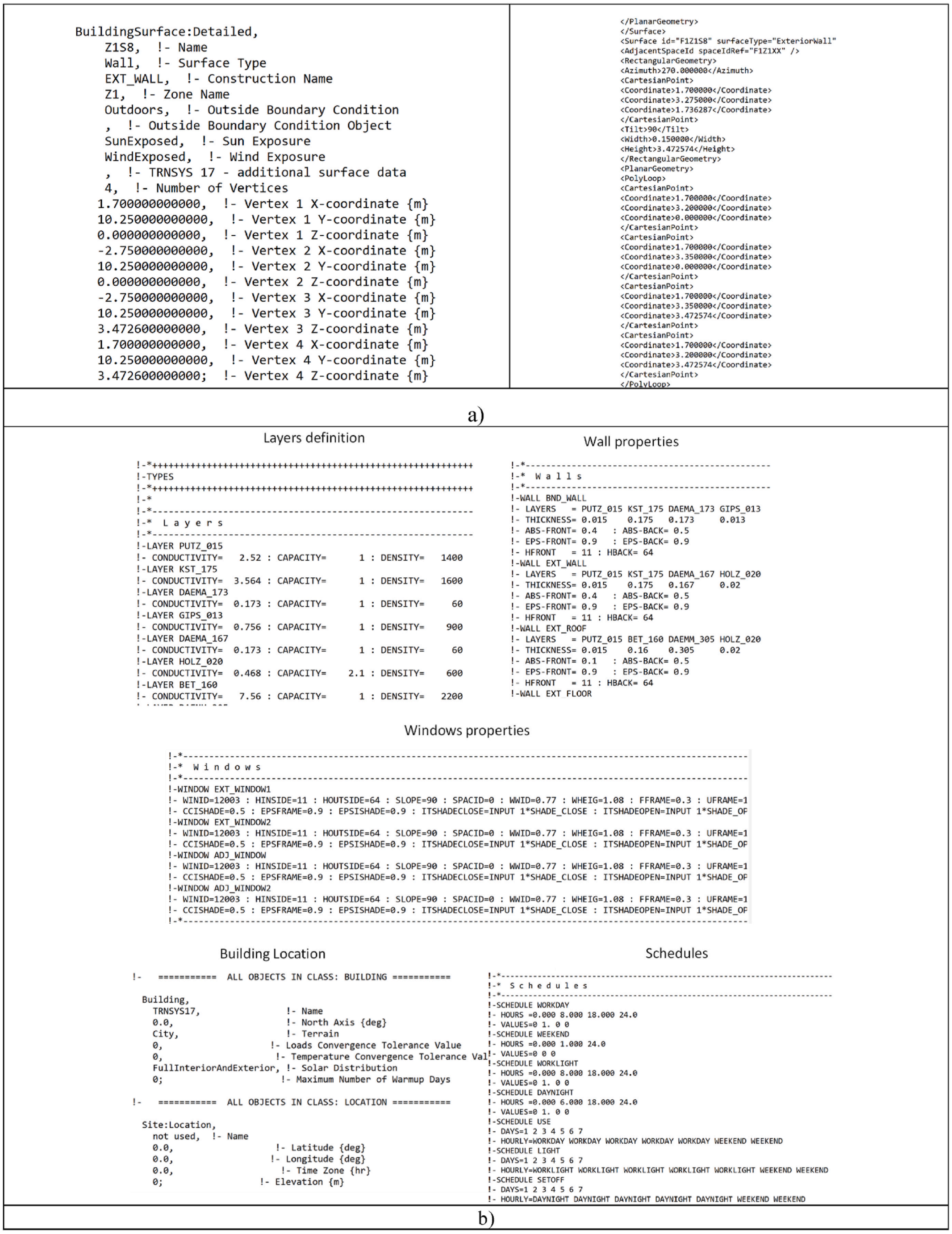
Fig. 9. a) Phases of geometric coupling between zones of the plant and final proprietary model of the plant. b) Details of the coupling: common vertices of faces for two and three zones.

	Zone 0	Zone 1	Zone 2	Zone 3	Zone 4
GROUND_FLOOR	Z0S0	Z1S0	…	…	…
EXT_ROOF	Z0S1	Z1S1	…	…	…
EXT_WALL	Z0S2, Z0S3, Z0S4, Z0S5 Z0S6, Z0S7	Z1S3, Z1S4, Z1S5, Z1S6, Z1S7, Z1S8,	…	…	…
ADJ_WALL	Z0S8 (ady. to Z1) Z0S9 (ady. to Z2)	Z1S2 (ady. to Z0) Z1S9 (ady. to Z2)	…	…	…
EXT_WINDOW1	Z0S5V0 (in Z0S5) Z0S5V1 (in Z0S5) Z0S5V2 (in Z0S5) Z0S5V3 (in Z0S5) Z0S5V4 (in Z0S5) Z0S5V5 (in Z0S5) Z0S9V0 (in Z0S9) Z0S9V1 (in Z0S9)	Z1S5V0 (in Z1S5) Z1S5V1 (in Z1S5) Z1S5V2 (in Z1S5) Z1S5V3 (in Z1S5) Z1S5V4 (in Z1S5) Z1S5V5 (in Z1S5) Z1S5V6 (in Z1S5) Z1S9V0 (in Z1S9) Z1S9V1 (in Z1S9)	…	…	…
EXT_WINDOW2	Z0S9P0 (in Z0S9) Z0S9P1 (in Z0S9)	Z1S9P0 (in Z1S9) Z1S9P1 (in Z1S9)	…	…	…

Fig. 10. Example of labelling of architectural elements obtained in zones 0 and 1 of the case study.

etary model to a standard energy model, which can be later used (imported) by engineering and construction professionals, and that can be denominated as a BEM model. These models cannot merely be used as geometric as-is models but can also be imported in order to carry out simulations and energy calibrations.

This paper presents a method that automatically generates a BEM file of an interior space of a building (typically a room or a set of rooms) in which, apart from the geometry, the temperature of the structural elements and other principal components (i.e., doors and windows) are also available with an approximate resolution of one datum per two square centimetres. Our research is specifically focused on developing a methodology that is able to generate BEM models (called in the paper as *PreBEM* models) from coarse data obtained from a thermal scanning system. The experimentation concerning the method presented has been successfully tested in scenar-



```
BuildingSurface:Detailed,
    Z1S8,  !- Name
    Wall,  !- Surface Type
    EXT_WALL,  !- Construction Name
    Z1,  !- Zone Name
    Outdoors,  !- Outside Boundary Condition
     ,  !- Outside Boundary Condition Object
    SunExposed,  !- Sun Exposure
    WindExposed,  !- Wind Exposure
     ,  !- TRNSYS 17 - additional surface data
    4,  !- Number of Vertices
   1.700000000000,  !- Vertex 1 X-coordinate {m}
   10.250000000000,  !- Vertex 1 Y-coordinate {m}
   0.000000000000,  !- Vertex 1 Z-coordinate {m}
   -2.750000000000,  !- Vertex 2 X-coordinate {m}
   10.250000000000,  !- Vertex 2 Y-coordinate {m}
   0.000000000000,  !- Vertex 2 Z-coordinate {m}
   -2.750000000000,  !- Vertex 3 X-coordinate {m}
   10.250000000000,  !- Vertex 3 Y-coordinate {m}
   3.472600000000,  !- Vertex 3 Z-coordinate {m}
   1.700000000000,  !- Vertex 4 X-coordinate {m}
   10.250000000000,  !- Vertex 4 Y-coordinate {m}
   3.472600000000;  !- Vertex 4 Z-coordinate {m}
```

```
</PlanarGeometry>
</Surface>
<Surface id="F1Z1S8" surfaceType="ExteriorWall"
<AdjacentSpaceId spaceIdRef="F1Z1XX" />
<RectangularGeometry>
<Azimuth>270.000000</Azimuth>
<CartesianPoint>
<Coordinate>1.700000</Coordinate>
<Coordinate>3.275000</Coordinate>
<Coordinate>1.736287</Coordinate>
</CartesianPoint>
<Tilt>90</Tilt>
<Width>0.150000</Width>
<Height>3.472574</Height>
</RectangularGeometry>
<PlanarGeometry>
<PolyLoop>
<CartesianPoint>
<Coordinate>1.700000</Coordinate>
<Coordinate>3.200000</Coordinate>
<Coordinate>0.000000</Coordinate>
</CartesianPoint>
<CartesianPoint>
<Coordinate>1.700000</Coordinate>
<Coordinate>3.350000</Coordinate>
<Coordinate>0.000000</Coordinate>
</CartesianPoint>
<CartesianPoint>
<Coordinate>1.700000</Coordinate>
<Coordinate>3.350000</Coordinate>
<Coordinate>3.472574</Coordinate>
</CartesianPoint>
<CartesianPoint>
<Coordinate>1.700000</Coordinate>
<Coordinate>3.200000</Coordinate>
<Coordinate>3.472574</Coordinate>
</CartesianPoint>
</PolyLoop>
```

a)

Layers definition

```
!-*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
!-TYPES
!-*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
!-*
!-*-------------------------------------------------------------
!-*  L a y e r s
!-*-------------------------------------------------------------
!-LAYER PUTZ_015
!- CONDUCTIVITY=   2.52 : CAPACITY=      1 : DENSITY=   1400
!-LAYER KST_175
!- CONDUCTIVITY=  3.564 : CAPACITY=      1 : DENSITY=   1600
!-LAYER DAEMA_173
!- CONDUCTIVITY=  0.173 : CAPACITY=      1 : DENSITY=     60
!-LAYER GIPS_013
!- CONDUCTIVITY=  0.756 : CAPACITY=      1 : DENSITY=    900
!-LAYER DAEMA_167
!- CONDUCTIVITY=  0.173 : CAPACITY=      1 : DENSITY=     60
!-LAYER HOLZ_020
!- CONDUCTIVITY=  0.468 : CAPACITY=    2.1 : DENSITY=    600
!-LAYER BET_160
!- CONDUCTIVITY=   7.56 : CAPACITY=      1 : DENSITY=   2200
```

Wall properties

```
!-*------------------------------------------------
!-*  W a l l s
!-*------------------------------------------------
!-WALL BND_WALL
!- LAYERS   = PUTZ_015 KST_175 DAEMA_173 GIPS_013
!- THICKNESS= 0.015    0.175   0.173     0.013
!- ABS-FRONT= 0.4   : ABS-BACK= 0.5
!- EPS-FRONT= 0.9   : EPS-BACK= 0.9
!- HFRONT   = 11 : HBACK= 64
!-WALL EXT_WALL
!- LAYERS   = PUTZ_015 KST_175 DAEMA_167 HOLZ_020
!- THICKNESS= 0.015    0.175   0.167     0.02
!- ABS-FRONT= 0.4   : ABS-BACK= 0.5
!- EPS-FRONT= 0.9   : EPS-BACK= 0.9
!- HFRONT   = 11 : HBACK= 64
!-WALL EXT_ROOF
!- LAYERS   = PUTZ_015 BET_160 DAEMM_305 HOLZ_020
!- THICKNESS= 0.015    0.16    0.305     0.02
!- ABS-FRONT= 0.1   : ABS-BACK= 0.5
!- EPS-FRONT= 0.9   : EPS-BACK= 0.9
!- HFRONT   = 11 : HBACK= 64
!-WALL EXT_FLOOR
```

Windows properties

```
!-*------------------------------------------------------------------------------------------------------------
!-*  W i n d o w s
!-*------------------------------------------------------------------------------------------------------------
!-WINDOW EXT_WINDOW1
!- WINID=12003 : HINSIDE=11 : HOUTSIDE=64 : SLOPE=90 : SPACID=0 : WWID=0.77 : WHEIG=1.08 : FFRAME=0.3 : UFRAME=1
!- CCISHADE=0.5 : EPSFRAME=0.9 : EPSISHADE=0.9 : ITSHADECLOSE=INPUT 1*SHADE_CLOSE : ITSHADEOPEN=INPUT 1*SHADE_OP
!-WINDOW EXT_WINDOW2
!- WINID=12003 : HINSIDE=11 : HOUTSIDE=64 : SLOPE=90 : SPACID=0 : WWID=0.77 : WHEIG=1.08 : FFRAME=0.3 : UFRAME=1
!- CCISHADE=0.5 : EPSFRAME=0.9 : EPSISHADE=0.9 : ITSHADECLOSE=INPUT 1*SHADE_CLOSE : ITSHADEOPEN=INPUT 1*SHADE_OP
!-WINDOW ADJ_WINDOW
!- WINID=12003 : HINSIDE=11 : HOUTSIDE=64 : SLOPE=90 : SPACID=0 : WWID=0.77 : WHEIG=1.08 : FFRAME=0.3 : UFRAME=1
!- CCISHADE=0.5 : EPSFRAME=0.9 : EPSISHADE=0.9 : ITSHADECLOSE=INPUT 1*SHADE_CLOSE : ITSHADEOPEN=INPUT 1*SHADE_OP
!-WINDOW ADJ_WINDOW2
!- WINID=12003 : HINSIDE=11 : HOUTSIDE=64 : SLOPE=90 : SPACID=0 : WWID=0.77 : WHEIG=1.08 : FFRAME=0.3 : UFRAME=1
!- CCISHADE=0.5 : EPSFRAME=0.9 : EPSISHADE=0.9 : ITSHADECLOSE=INPUT 1*SHADE_CLOSE : ITSHADEOPEN=INPUT 1*SHADE_OP
!-*------------------------------------------------------------------------------------------------------------
```

Building Location

```
!-   ===========  ALL OBJECTS IN CLASS: BUILDING ===========

  Building,
    TRNSYS17,                  !- Name
    0.0,                       !- North Axis {deg}
    City,                      !- Terrain
    0,                      !- Loads Convergence Tolerance Value
    0,                       !- Temperature Convergence Tolerance Val
    FullInteriorAndExterior, !- Solar Distribution
    0;                        !- Maximum Number of Warmup Days

!-   ===========  ALL OBJECTS IN CLASS: LOCATION ===========

  Site:Location,
    not used,  !- Name
    0.0,                     !- Latitude {deg}
    0.0,                    !- Longitude {deg}
    0.0,                      !- Time Zone {hr}
    0;                    !- Elevation {m}
```

Schedules

```
!-*---------------------------------------------------------------------
!-*  S c h e d u l e s
!-*---------------------------------------------------------------------
!-SCHEDULE WORKDAY
!- HOURS =0.000 8.000 18.000 24.0
!- VALUES=0 1. 0 0
!-SCHEDULE WEEKEND
!- HOURS =0.000 1.000 24.0
!- VALUES=0 0 0
!-SCHEDULE WORKLIGHT
!- HOURS =0.000 8.000 18.000 24.0
!- VALUES=0 1. 0 0
!-SCHEDULE DAYNIGHT
!- HOURS =0.000 6.000 18.000 24.0
!- VALUES=0 1. 0 0
!-SCHEDULE USE
!- DAYS=1 2 3 4 5 6 7
!- HOURLY=WORKDAY WORKDAY WORKDAY WORKDAY WORKDAY WEEKEND WEEKEND
!-SCHEDULE LIGHT
!- DAYS=1 2 3 4 5 6 7
!- HOURLY=WORKLIGHT WORKLIGHT WORKLIGHT WORKLIGHT WORKLIGHT WEEKEND WEEKEND
!-SCHEDULE SETOFF
!- DAYS=1 2 3 4 5 6 7
!- HOURLY=DAYNIGHT DAYNIGHT DAYNIGHT DAYNIGHT DAYNIGHT WEEKEND WEEKEND
```

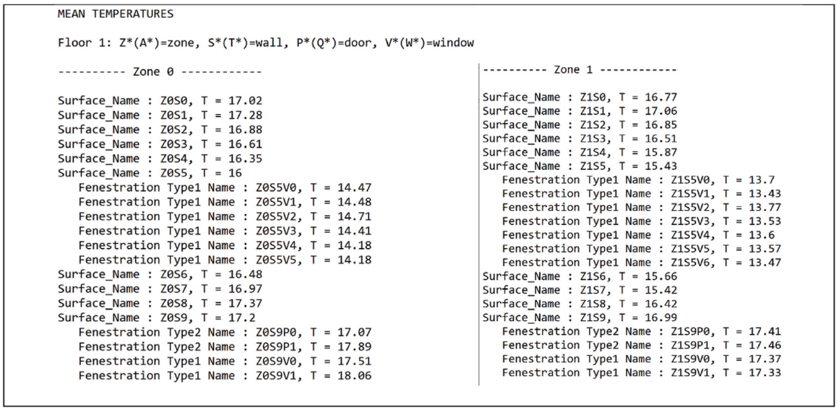
b)

Fig. 11. a) Examples of text generated in *PreBEM_2* (left) and *PreBEM_1* (right) formats, referring to one of the walls in Zone 1. Each file has its own coordinate origin. b) Code concerning some non-geometric information: layers, wall properties, window properties, building, location and schedules.

ios with the scope of the floor of a building, with the *PreBEM_1* and *PreBEM_2* files being imported into EnergyPlus and TRNSYS respectively.

The huge amount of thermal information contained in the thermal point clouds collected can be used to detect and locate (delimit) regions of thermal leaks, thermal bridges, and temperature gradient regions in the 3D thermal model. However, this paper focuses on reducing the lack of mono-directional interoperability between proprietary models, which are obtained by means of reverse engineering, and standard models that are imported by the tools of energy applications.

Although we have reached the point of being able to automatically obtain such BEM models, there is still much work to do. Improvements to the current development are focused on several lines. One of the most difficult issues as regards the transition from



```
MEAN TEMPERATURES

Floor 1: Z*(A*)=zone, S*(T*)=wall, P*(Q*)=door, V*(W*)=window

---------- Zone 0 ------------

Surface_Name : Z0S0, T = 17.02
Surface_Name : Z0S1, T = 17.28
Surface_Name : Z0S2, T = 16.88
Surface_Name : Z0S3, T = 16.61
Surface_Name : Z0S4, T = 16.35
Surface_Name : Z0S5, T = 16
   Fenestration Type1 Name : Z0S5V0, T = 14.47
   Fenestration Type1 Name : Z0S5V1, T = 14.48
   Fenestration Type1 Name : Z0S5V2, T = 14.71
   Fenestration Type1 Name : Z0S5V3, T = 14.41
   Fenestration Type1 Name : Z0S5V4, T = 14.18
   Fenestration Type1 Name : Z0S5V5, T = 14.18
Surface_Name : Z0S6, T = 16.48
Surface_Name : Z0S7, T = 16.97
Surface_Name : Z0S8, T = 17.37
Surface_Name : Z0S9, T = 17.2
   Fenestration Type2 Name : Z0S9P0, T = 17.07
   Fenestration Type2 Name : Z0S9P1, T = 17.89
   Fenestration Type1 Name : Z0S9V0, T = 17.51
   Fenestration Type1 Name : Z0S9V1, T = 18.06

---------- Zone 1 ------------

Surface_Name : Z1S0, T = 16.77
Surface_Name : Z1S1, T = 17.06
Surface_Name : Z1S2, T = 16.85
Surface_Name : Z1S3, T = 16.51
Surface_Name : Z1S4, T = 15.87
Surface_Name : Z1S5, T = 15.43
   Fenestration Type1 Name : Z1S5V0, T = 13.7
   Fenestration Type1 Name : Z1S5V1, T = 13.43
   Fenestration Type1 Name : Z1S5V2, T = 13.77
   Fenestration Type1 Name : Z1S5V3, T = 13.53
   Fenestration Type1 Name : Z1S5V4, T = 13.6
   Fenestration Type1 Name : Z1S5V5, T = 13.57
   Fenestration Type1 Name : Z1S5V6, T = 13.47
Surface_Name : Z1S6, T = 15.66
Surface_Name : Z1S7, T = 15.42
Surface_Name : Z1S8, T = 16.42
Surface_Name : Z1S9, T = 16.99
   Fenestration Type2 Name : Z1S9P0, T = 17.41
   Fenestration Type2 Name : Z1S9P1, T = 17.46
   Fenestration Type1 Name : Z1S9V0, T = 17.37
   Fenestration Type1 Name : Z1S9V1, T = 17.33
```

Fig. 12. Text file with average temperatures (°C) of the elements of zones 0 and 1.

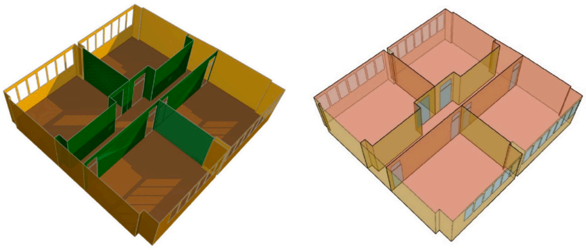
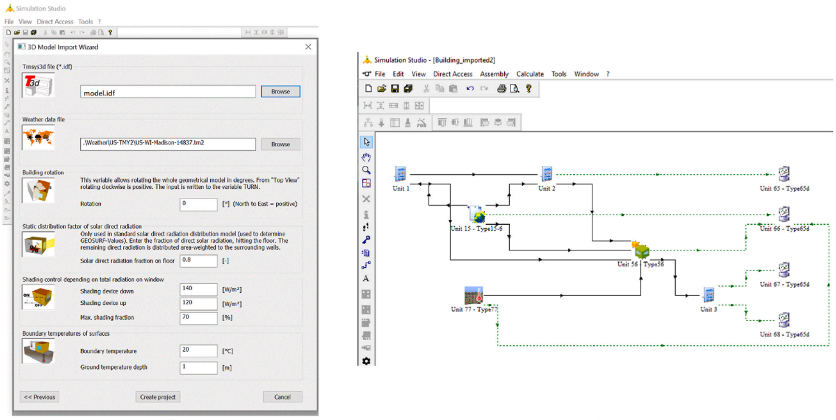


Fig. 13. Design Builder viewer (for *PreBEM_1*) and Sketchup for TRNSYS viewer (for *PreBEM_2*).



Trnsys3d file (*.idf): model.idf

Weather data file: .\Weather\US-TMY2\US-WI-Madison-14837.tm2

Building rotation

This variable allows rotating the whole geometrical model in degrees. From "Top View" rotating clockwise is positive. The input is written to the variable TURN.

Rotation: 0 [°] (North to East = positive)

Static distribution factor of solar direct radiation

Only used in standard solar direct radiation distribution model (used to determine GEOSURF-Values). Enter the fraction of direct solar radiation, hitting the floor. The remaining direct radiation is distributed area-weighted to the surrounding walls.

Solar direct radiation fraction on floor: 0.8 [-]

Shading control depending on total radiation on window

Shading device down: 140 [W/m²]
Shading device up: 120 [W/m²]
Max. shading fraction: 70 [%]

Boundary temperatures of surfaces

Boundary temperature: 20 [°C]
Ground temperature depth: 1 [m]

a)   b)

Fig. 14. Example of integration of *PreBEM_2* into TRNSYS. a) Creation of a TRNSYS project and b) Simulation outline, including specific inputs and outputs.

TPM to BEM is that of efficiently solving the requirement of closed volume in the whole model (requirement R2). When the scenario is composed of several rooms, with walls that have more than one adjacent wall, the current algorithm needs to split the multi-adjacent wall and generate virtual new rooms in order not to be incongruence in the IDF file. This process may, at some points, require the help of the programmer in order to ensure that the former and new vertices correspond. We shall, therefore, investigate with the aim of improving the automation of this stage. Furthermore, the automatic insertion of the sensed temperatures or other energy parameters calculated from our thermal model (e. g. transmittance) into current energy simulation software is also a new challenge to be confronted in the following months. Finally, we wish to deal with more standard BEM formats and to extend the scope of our research to a multi-storey environment with a more complex geometry.

Author statement

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Universidad de Castilla La Mancha reports financial support was provided by Spain Ministry of Science and Innovation.

Data availability

Data will be made available on request.

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