When implementing energy-efficient housing concepts in practice, designers often apply an object-centred design approach that generates a static built environment, causing higher material consumption, building costs and actual energy demands when the building is in use. To provide an alternative solution for current energy-efficient renovation concepts, previous research suggests a user-centred approach which considers dynamic residents and varying conditions throughout the seasons. The approach aims to promote more efficient occupant behaviour to decrease the actual energy demand by enabling a dynamic way of living throughout the seasons. The research hypothesis is that decreasing the actual energy demand of the resident by means of a user-centred design approach can limit the need for additional quantities of materials and renovation costs (resource-efficiency). In this context, the shift from an object-centred approach for energy-efficiency to a user-centred approach for resource-efficiency is tested by means of an educational study within the design studio ‘Zero Pentathlon: sustainable housing renovation’ at Hasselt University, Belgium. The paper presents a critical reflection on the students’ analyses of dynamic residents, the resulting dynamic design concepts, and the effect of the user-centred approach on the energy-efficiency of the building. The paper finds that the resulting designs which best enable a dynamic way of living throughout the seasons come from students who analysed the dynamic properties of residents more in-depth. These designs promote efficient occupant behaviour and show potential to contribute to the energy-efficiency of the building. However, it is also concluded that it was challenging for all students to create a synergy and incorporate both the analysis of residents and the analysis of the built environment within a resource-efficient building design. The findings will serve as input for future research to further develop an alternative user-centred design methodology for resource-efficient building.
1 Introduction

1.1 From an object-centred to a user-centred design approach in resource-efficient renovations

Due to environmental, economic and social developments, the traditional detached single-family dwelling, a common housing model in Flanders, is under pressure (Bervoets & Heynen, 2013; Gerards, De Ridder, & De Bleeckere, 2015; van de Weijer, 2014). With a larger average living space than other housing models (e.g. terraced houses), these dwellings bring forth a high total environmental impact (energy and material consumption) and have higher renovation costs (ADS, 2014; Verbeeck & Ceulemans, 2015). Furthermore, 40% of these large, detached single-family dwellings are underused due to demographic trends such as decreasing household sizes (Bervoets, 2014; van de Weijer, 2014). This can result in inefficient heating and occupation of a large building volume and leads to large actual energy demands. The Flemish Housing Policy is currently aiming at more affordable, quality and sustainable housing, with a strong focus on energy efficiency (Vlaamse Overheid, 2015). This resulted in the implementation of energy-efficient housing concepts (e.g. passive housing and low-energy housing) which generate new challenges such as higher material consumption and renovation costs (Audenaert, De Cleyn, & Vankerckhove, 2007; Hollberg & Ruth, 2016).

The currently imposed energy-efficiency measures focus mostly on optimization of the building skin by applying large quantities of additional materials and active systems which is referred to as an object-centred approach for energy-efficient building (Author, 2017). Furthermore, other parameters that influence the energy demand, such as outdoor climate and residents, are often seen as static in this object-centred approach (Author, 2017). Moreover, the lack of user interaction that results from this approach can induce inefficient user practices which can lead to an increase in actual energy demand (Gram-Hanssen, 2013). So, while the current and commonly used object-centred approach focuses on providing an energy-efficient supply, based on (Bierwirth & Thomas, 2015; Cauberg, 2016; Rovers, 2015; Thomas & Brischke, 2015) we suggest to promote more sufficient energy demand by considering dynamic residents.

Based on a literature study (Bosserez, Verbeeck, & Herssens, 2017), this paper proposes a shift from the object-centred to user-centred approach for energy-efficient building by suggesting the application of an alternative design methodology which analyses not only objects but also users and considers their needs to allow for more energy-efficient user interaction with the built environment. This user-centred approach proposes to consider the residents as dynamic and takes their behaviour into account in the buildings’ design by enabling a dynamic way of living throughout the seasons. From the literature study, three design criteria are derived which aim for: 1) varying indoor climatic conditions for efficient heating of spaces; 2) an adapted space plan for diversified occupation of spaces throughout the seasons; and 3) support of the resident for more environmental experience and user satisfaction. The research hypothesis is that the user-centred approach can decrease the actual energy demand and lead to an energy-efficient design which limits the need for large amounts of additional materials when optimizing the building skin. This alternative user-centred approach is tested within an architectural design studio, Zero Pentathlon, to explore what information is generated from analysis of dynamic residents and how this is considered within a design for energy-efficiency.

1.2 The design studio Zero Pentathlon

For several years, the design studio of Zero Pentathlon has addressed current environmental challenges such as climate change and depletion of natural resources by investigating sustainable residential renovations. First year master students of Architecture, organized in 7 groups of 5 students, are assigned to renovate an existing dwelling into a zero-energy building with a minimal impact on water and material use. During the design studio students are guided by means of tutoring sessions, lectures and workshops on related topics. The assignment’s requirement is
twofold: a logical constructive and architectural dynamic design for resource-efficient renovation. By applying a user-centred approach, students are required to come to a synergy of two approaches where the built environment as well as the dynamic resident and varying seasons are taken into account (Figure 1). The architectural dynamic design concept should contribute to the decrease of the actual energy demand in such a way that the need for large amounts of additional materials and active systems is limited within the constructive design.

![Design studio Zero Pentathlon](image)

*Figure 1 Shifting from an object- to a user-centred approach within the design studio Zero Pentathlon*

The *constructive design* aims for decreasing the total environmental impact. Students need to analyse an existing, large, underused, detached, single-family dwelling in the region of Flanders by means of calculations of material, energy and water consumption and in-depth description of the buildings’ construction. Then, students are encouraged to develop a constructive building design by implementing the PENTA-strategy to reach optimal sustainability. The strategy is based on the TRIAS-strategies (energetica, materia, aquatica) and is supplemented by an “from passive to active” approach where physical-spatial measures are integrated with constructive-technical measures.

The *architectural dynamic design* focuses on decreasing the actual energy demand by enabling a dynamic way of living throughout the seasons which promotes efficient heating and occupation of spaces. The students are provided with a design methodology which is divided in two main phases: analysis and design. They are required to analyse the dynamic aspects of the seasonal living pattern of current residents as follows: (1) Collection of data on occupant behaviour by means of semi-structured interviews (pre-scripted by instructors); (2) Visualization of the collected data by means of a mapping-method (selected by students); (3) Interpretation of the collected data and description of the seasonal living pattern; (4) Establishing case-specific design requirements which respond to dynamic residents to implement in design phase. Based on the results of the analysis of the existing situation, students are requested to create an innovative renovation concept which allows for a more dynamic and efficient use of the large, underused, living environment throughout the seasons based on three user-centred design criteria mentioned above (Bosserez et al., 2017). The resulting energy-efficient design concept and dynamic spatial use of the renovated living environment needed to be presented through visualizations. In addition, a description of the applied design strategies and measures which link the dynamic design concept to energy-efficiency is requested.
The design studio provides an observational setting when shifting from an object- to a user-centred approach for resource-efficiency. The paper aims to elicit information on barriers and needed improvements for future research and further development of the alternative design methodology which enables a dynamic way of living throughout the seasons. Therefore, the paper presents an analysis of the students’ design process (from context analysis to concept design) and the resulting design concepts of Zero Pentathlon. It critically reflects on the analysis of the existing residents’ seasonal living pattern, how dynamic properties of residents are considered within the design and how that affects the energy-efficiency of the building.

2 Method
The results of the design studio are analysed by means of students’ final reports, observations during the tutoring sessions and posters of the final jury. The criteria presented in Table 1 are based on the design assignment and used to critically reflect on the design process and resulting designs of students.

Table 1. Criteria used for critical reflection on the design process and resulting architectural design concepts of students within the design studio Zero Pentathlon

<table>
<thead>
<tr>
<th>Analysis of the dynamic resident</th>
<th>Results from analysis</th>
</tr>
</thead>
</table>
| Collection of data: transcriptions and summaries of interviews | • The presented properties of dynamic residents  
• The representation of the dynamic aspects  
• Description of comfort needs and spatial preferences of residents |
| Visualization of data: maps on occupant behaviour |  |
| Interpretation of data: analysis of seasonal living pattern | • The properties which define the seasonal living pattern according to the students  
• The influence of the seasonal living pattern on the actual energy demand according to the students |
| Design for enabling a dynamic way of living throughout the seasons |  |
| Implementation of information from analysis within design | • Application of insights from analysis of residents within the design |
| Design concept response to dynamic residents | • Concept for responding to dynamic residents throughout the seasons |
| Contribution to energy-efficiency of the resulting concepts and applied principles | • Potential impact of the resulting concepts and applied principles on the actual energy demand of residents |
| Integration of dynamic design concept into a holistic sustainable renovation | • Integration of the dynamic and the constructive designs within the entire design project |

3 Results and discussion
3.1 Collection of data
The students’ transcriptions of the interviews entail information on the profile of the residents, the occupation and heating of spaces and the residents’ comfort needs. The analysis of the transcription shows that all residents were retired couples or individuals, with children who had left the house many years earlier. Daily activities and hobbies include cooking, reading and watching TV and occur mostly in the common living areas (e.g. kitchen and living room).

All residents experience their living environment as too large as the dwelling contains several vacant and underused rooms. The latter are often second living rooms or former bedrooms of their children which currently have a flexible function as they can be used as storage room, guest bedroom or for family gatherings when needed. However, in general the indoor living environment is considered static and non-adaptable because of the small, enclosed rooms and the solid walls which do not
allow expansion and reduction of spaces when needed (e.g. family gatherings). According to the residents missing functions include a glass-enclosed veranda or winter garden with optimal thermal comfort, and a convenient office and hobby space. Furthermore, in one third of the cases the residents only want to use the ground floor to increase functional comfort in view of ageing, thus leaving nearly half of the living area unoccupied.

Besides functional comfort, thermal comfort levels are not perceived as ideal throughout the year. In most cases, the living room and veranda are experienced too hot in summer and too cold in winter, also bedrooms are often experienced too cold. Responses to such discomfort often include closing doors, opening windows and turning on stoves. In one household, residents switch from the bedroom on the north to one in the south in winter for improvement of thermal comfort. In addition to thermal and functional comfort, residents often refer to the connection with the outside and the need for plenty of daylight. Consequently, all residents migrate from the living room in winter to the garden or veranda in summer.

When the living room is too cold in winter, most residents have additional local heating (e.g. wood stove) for more heat and cosiness. In summer, when the veranda is too hot, no active cooling is applied, instead residents put down blinds and close windows and doors to block the sun. In general, the thermostat is not adjusted and residents keep a constant indoor climate throughout the year, except for additional heating (e.g. stoves) in winter.

The transcriptions contain information on occupant behaviour (heating and occupation), personal comfort needs and spatial preferences. In addition, dynamic elements are found such as diversified occupation and varying heating of spaces in summer and winter. However, most students' final reports are limited to only transcriptions of the interviews. In addition, some groups added very short descriptive summaries or general conclusions. During this first step within the design process, students were not reflecting on the influence of occupant behaviour on the energy demand. However, when collecting data on the building itself for the constructive design, students already reflected on the environmental impact of the obtained data.

### 3.2 Visualization of data

All students visualized the obtained data by means of drawings or sketches of the floorplans. Most data are visualized by marking/highlighting different spaces on the floorplan. The type of data which are mapped include: circulation routes, favourite spots of residents, spaces with adequate comfort, occupation rate, and heating of rooms. Data on heating, occupation and thermal comfort of spaces are mapped most often and different ranges and units for mapping these properties were used (Figure 2).

These included highlighting the often, rarely, or non-occupied spaces and heated and non-heated spaces. During the tutoring sessions, students reflected on the latter to gain more insights on relationship between the spatial use and the heating of the existing living environment. However, half of the students’ reports lacked the proper legends and additional information on which properties were mapped and why they are relevant (e.g. residents’ favourite spots and circulation routes). Overall, it appeared challenging for students to properly map the gained information of the living pattern and interpret the maps in view of energy-efficiency. This can be explained by the general lack of knowledge of students on the influence of occupant behaviour on the actual energy demand.
To present the dynamic elements of residents’ living pattern, students developed multiple floorplans on one property of the living pattern (e.g. occupation of rooms), by making distinctions between winter and summer, day and night and weekdays and weekend. However, during the tutoring sessions within the design studio, the students’ scope of analysis was too wide to select relevant data for which they struggled to represent or visualize all the dynamics within residents’ living pattern. Therefore, seasonal time boundaries remain important to avoid that all dynamics are visualized separately (e.g. day/night maps and summer/winter maps), and instead are viewed throughout the seasons (e.g. differences between days or nights in summer and days or nights in winter).

There was a distinction between groups of students in the use of the mapping method. Two student groups used the mapping method to only process data by means of visualization. These two groups are referred to as cluster A in the rest of the paper. The five other student groups also used the maps for analysing the seasonal living pattern of residents. These five groups are referred to as cluster B. Cluster A developed rather static or a limited amount of maps and relied more directly on the knowledge gained from the interviews to further analyse the residents. The more nuanced and dynamic maps belonged to the latter, cluster B. Some of the students from cluster B visualized the information gathered on the built environment such as location and amount of heating systems,
load-bearing structures and ventilation which affected the analysis of seasonal living pattern. The latter is further discussed in the following section.

### 3.3 Interpretation of data

Students in cluster B analysed the seasonal living pattern based on interpretations of the conducted interviews and the resulting maps. The properties which mostly defined the derived seasonal living pattern are occupation and heating of rooms. The analyses of cluster A on occupation of rooms are limited to descriptions of which rooms are (not) underused. The analyses of cluster B are more nuanced as they also described how often rooms are used and when. The occupation rate of rooms is occasionally explained by the thermal comfort of residents (e.g. the living rooms is not used as it is too cold). In addition, when the duration of occupation is mentioned, it is always linked to the residents’ activities in the room (e.g. the office is only shortly used when reading e-mails and the living rooms is used for a longer time when watching TV). The analysis of heating of rooms is linked to the functions of rooms (e.g. circulation spaces are not heated). Furthermore, occupation of rooms is also linked to the heating of rooms (e.g. the bathroom is only heated when occupied). In addition, some students of cluster B analysed the organization of heated and non-heated rooms (e.g. the often heated rooms are not grouped together). The latter is a direct interpretation of the mapped floorplans. Besides the description of occupation and heating of rooms, half of the students of cluster B reflected on the influence on the energy-efficiency of residents’ living pattern (e.g. the heated rooms are not zoned together which causes unnecessary heat losses to less occupied and non-heated rooms).

Students from cluster A directly rely on the interpretation of the interviews’ transcription for the analysis of the seasonal living pattern while students from cluster B also interpreted the maps as part of the analysis. The latter have a more nuanced analysis as they correlated the heating, occupation and thermal comfort of spaces. Two of those five groups also mapped properties of the built environment (e.g. amount, type and location of heating systems) and described which heating systems are in use, when they are used, and how that room is occupied. Furthermore, within students’ reports of cluster B, preliminary ideas and strategies to increase energy-efficiency are mentioned (e.g. often heated rooms can be zoned together to avoid extensive heat losses). Other students from cluster A and B did not implement strategies to improve the functional comfort of residents (e.g. sound-proofing the walls to block noise from the living room to the kitchen or move bathroom downstairs as a response to immobile resident). Students from cluster A who did not include a critical reflection on the analysed seasonal living pattern, lacked relevant insights on the influence of the occupant behaviour on space- and energy-efficiency. These students struggled with mapping and correctly interpreting these maps to derive the residents’ seasonal living pattern. Although the descriptions on the seasonal living pattern of cluster A are limited, from the resulting transcriptions and maps, dynamics of the occupant behaviour are effectively detectable, but the students were not able to do so. Cluster A, which based the analysis on the interpretation of interviews and maps gained more insights on the seasonal living pattern and the dynamics of occupant behaviour. As several studies (Gram-Hanssen, 2010; van Dronkelaar, Dowson, Spataru, & Mumovic, 2016) on occupant behaviour indicate, there are properties such as heating and occupation of rooms which influence the actual energy demand of the building. The following section will discuss further whether mapping and analysing the dynamic way of living throughout the seasons of existing residents can improve the dynamic design and its impact on energy-efficiency.

### 3.4 Synthesis of analysis

After the analysis of the seasonal living pattern, four student groups (all from cluster B) evaluated if the current built environment responds to the dynamic elements of residents living. Cluster A who did not interpret maps or reflect on the seasonal living pattern, did not manage to set up explicit design requirements.
The main conclusions students derived from the analysis of residents is that the living environment is too large, therefore not adapted, and it consists of small and static rooms. As a response, several students from cluster B derived flexible walls and adaptability of the spatial plan as design requirements. These design requirements all relate to adapting the structure, spatial plan and heating systems of specific spaces within the living environment. From the analysis of the building for the constructive part of the design studio, students from cluster A and B conclude that the existing situation leads to high heat losses. The most common responses are wrapping up the entire building volume by adding insulation, applying solar panels and implementation of mechanical ventilation. This and several other derived design requirements relate to the building skin and systems.

![Diagram of design process and analysis phase](image)

Figure 3 Overview of the relation to the built environment of design requirements from cluster A and cluster B after the analysis phase

It can be concluded that cluster B, students who analysed the dynamic properties of residents more in-depth, are not only considering the building skin and systems but also the structure and spatial plan when transitioning to the design phase (Figure 3). Furthermore, cluster B’s results in this stage of the design process show more potential on enabling a dynamic way of living throughout the seasons rather than developing a constant, static and controlled living environment as seen in object-centred approaches. However, whether the analysis of residents effectively leads to dynamic design concepts and contributes to the buildings’ energy-efficiency is further explored in the following sections on the resulting designs.

### 3.5 Dynamic design concept: responding to dynamic residents and varying seasons

In general, two main architectural design concepts resulted from the design studio: multi-unit dwelling and the greenhouse dwelling. Five of seven student groups (cluster A and B) responded to the underused living space by dividing the building in two living units, one unit for the existing residents and one mostly for starting families. The multi-unit designs have flexible rooms such as
additional living space, work spaces or ateliers which can be used by both residential units when needed. The remaining students (cluster B) implemented greenhouse structures within their design. One student cluster from cluster B even combined the multi-unit concept with a greenhouse which serves as a buffer between protected and non-protected volumes (Figure 5). The other students (cluster B) applied the greenhouse concept as an extension of the living area where it serves as a seasonally adaptable space.

Both concepts respond differently to the residents’ living pattern for which two interpretations of the residents’ dynamism arise. Within the multi-unit concept, the dynamism of residents’ occupation is viewed on the long term. When the household size changes (e.g. empty nest), the dwelling is adapted by dividing it into several living-units (e.g. Figure 4). In addition, the flexible rooms respond to a short term dynamism within the household size, for instance, when occasionally a larger living room is required for family gatherings, a playroom for grandchildren or for meetings.

Within the greenhouse concept, the design responds to seasonal dynamics (e.g. Figure 5). Most students’ analysis of the seasonal living pattern shows that in winter the living room is used as the main living area while in summer, residents migrate to the terrace, garden or the glass-enclosed veranda to be more connected to the outside. The latter is preferred by residents as the main living area, but in other seasons, it is too cold. Therefore, students (cluster B) suggest the greenhouse to serve as the main living area throughout the seasons and increase the connection with outside. The greenhouse differs from the traditional glass-enclosed veranda as it serves as an adequate living space. The greenhouse is incorporated within the building skin and spatial plan, it is part of the protected volume and constructed with insulating glass. In addition, it enhances the connection between indoor and outdoor living environment and visual comfort.

Figure 4 Multi-unit dwelling designed by Dupont Yves, Janssen Sascha, Poolini Laura, Peulen Sandrine, Verheyen Femke
3.6 The link between the dynamic design concept and energy-efficiency

Besides increasing space-efficiency, the multi-unit concept increases energy-efficiency by dividing the living area and total energy demand among more residents. However, by minimizing the living area per resident, the multi-unit designs also limit the dynamic way of living throughout the seasons. So, although the multi-unit concept resolved the underuse of the living area, it created an obstacle for students from cluster A to enable a dynamic way of living throughout the seasons. Due to limited living space per resident, students designed rooms to become more static and created a constant, isolated indoor climate which is not in dialogue with the seasons. In general, multi-unit may contribute to lowering the environmental impact of dwellings, but it is intrinsically focused on improving social sustainability (Gerards, 2016; van de Weijer, 2014), whereas enabling a dynamic way of living throughout the seasons aims at reducing the actual energy demand by heating and occupying spaces more efficiently. Nevertheless, both are responding to dynamic residents which can provide confusion when applying a user-centred design approach.

The greenhouse is intended by students from cluster B as a climatic buffer between outdoors and indoors (Figure 6) or protected and non-protected building volumes. The greenhouse intercepts thermal differences in order to provide optimal indoor climatic. It considers the dynamic occupation of rooms throughout the seasons and simultaneously lowers the need for active cooling or additional heating of rooms. The latter is achieved by transporting the stored heat during intermediate seasons to the colder rooms of the indoor living environment (Figure 6). Despite the fact that the greenhouse can become too cold during winters because it is heated only by solar gain and not actively, it can be occupied during all other seasons and it improves the experience of the living environment by increasing the connection to the outside.
Besides the previous strategies that the students presented as their main design concepts, smaller interventions are found within the resulting designs. Firstly, the occupation rate of spaces and the heating of rooms are combined in order to group these rooms together into zones and provide a more compact heated volume. In addition, day and night functions and cold and warm areas are grouped together to prevent heat loss and provide optimal heating distribution. These principles are also known as thermal zoning within climate-responsive building and are shown to contribute to the energy-efficiency of buildings (DeKay & Brown, 2014). Secondly, flexible rooms, that can be enlarged or reduced, are designed to provide appropriate and more efficient acclimatization of rooms when occupation rates change. The effectiveness of this intervention depends on the occupant behaviour. For instance, if residents do not shrink the room when the number of occupants is low, unnecessary heat losses can occur to the underused parts of the room. Thirdly, a more innovative intervention was applied where heating systems were linked to the duration and frequency of occupation to provide more dynamic heating. For instance, in rooms which are constantly occupied and need higher temperatures in winter, floor heating was applied. Whereas in rooms which are only shortly or irregularly occupied, infra-red panels, which can heat up and cool down faster, are applied.

3.7 Implementation of the analysis of seasonal living pattern in the design

Cluster A produced two multi-unit designs. One of the designs also included flexible rooms which aim for acclimatization adjusted to the occupation rate of the room. The other design in cluster A did not further apply measures which promote dynamic and efficient use of spaces. Cluster A’s reports contain insufficient analysis of the existing residents. Their resulting dynamic designs seem to have a limited impact on the energy-efficiency of the building.

Cluster B submitted five designs of which two are greenhouse concepts that respond to the seasonal living pattern of residents. Both these designs apply the principle of thermal zoning which can
decrease the energy demand. Two other designs are based on the multi-unit concept which responds less to the dynamic way of living throughout the seasons. However, the principle of thermal zoning was also applied within these two designs to improve efficient heating and occupation of the indoor living environment. The fifth design is a combination of the multi-unit and the greenhouse concept. As an additional intervention, this design proposes dynamic heating by means of infra-red panels as a response to the varied occupation of spaces by the residents.

The analysis on consideration of dynamic residents within an energy-efficient design shows that cluster B, which are students who conducted a more in-depth analysis of the existing residents, developed designs which fitted the aim of enabling a dynamic way of living throughout the seasons the most. These are also the designs that have the most potential to decrease the actual energy demand of the building. It appears that the visualization of the data by means of mapping improves the analysis of the seasonal living pattern. The designs of cluster A, which are characterized by a more limited analysis of the residents, are responding less to the dynamic properties of residents which can influence the energy demand (e.g. heating and occupation of spaces). However, within the collected data of these students, several dynamics within the living pattern of residents are detected. From observations during tutoring sessions it is noticed that cluster A spent less time on the analysis of residents (user-centred) and kept a strong focus on the analysis of the building (object-centred). This approach created an obstacle for the cluster A students to design an energy-efficient living and built environment which responds to dynamic residents and varying seasons.

Exploring the application of analysis on dynamic residents within the design showed that cluster A, which lacked in-depth analysis of residents by means of the provided methodology did not create designs which respond to dynamic residents and their seasonal living pattern to decrease energy demand. Cluster B, which did carry out an in-depth analysis of dynamic resident behaviour had designs which enabled a dynamic way of living throughout the seasons and showed potential to increase energy-efficiency.

3.8 Object-centred versus user-centred approach

This paper reflects on the integration of the dynamic design and the constructive design within the entire design studio of Zero Pentathlon. Besides the architectural design concepts also constructive designs by all students are developed to increase energy-efficiency by applying measures such as insulated exterior walls, mechanical ventilation systems, heat pumps and solar panels and solar boilers. In addition, an increase in material-efficiency was created by reusing materials (e.g. bricks which were removed to apply insulation were used again as finishing for exterior walls) and used sustainable materials when additional materials were needed. During the tutoring sessions it is noted that the constructive and dynamic part of the design studio are designed separately rather than in synergy. However, the initial goal of the alternative user-centred approach was to shift away from an object-centred approach and limit the need for large quantities of additional materials by promoting more efficient occupant behaviour and decreasing the actual energy demand. It appeared highly challenging for all students to create a synergy where the dynamic design and constructive design complement each other.

Due to a small number of participants (35 students), the results (7 designs) of the educational study are limited. In addition, the design studio is organized in a Flemish context which can contain different design approaches in terms of functionality and for energy-efficient housing compared to an international context. Nevertheless, the study introduces a method for analysing residents when developing an energy-efficient building. Furthermore, illustrative design examples are presented on the integration of building, resident and climate within sustainable building. The study provides relevant insights on obstacles for designers when shifting from an object- to a user-centred design approach.
4 Conclusions

This paper explored the implementation of a user-centred approach for resource-efficient renovation within an architectural design studio for first year Master students. The alternative approach aims to counteract the challenges currently occurring within an object-centred approach for energy-efficient building. The user-centred approach aims at responding to dynamic residents and varying seasons to induce user interaction and thus promote space- and energy-efficiency. First, students needed to analyse the seasonal living pattern of existing residents by means of interviews and mapping of the occupant behaviour in winter and summer. Secondly, the students had to integrate the analysis of dynamic residents within a resource-efficient design. In Table 2, the main results from the analysis- and design-phase of the different student groups are presented. A distinction is made between cluster A, and cluster B which conducted a more in-depth analysis of the existing residents.

Table 2 Overview of results from analysis and design phase divided in two groups

<table>
<thead>
<tr>
<th></th>
<th>Cluster A (2 student groups)</th>
<th>Cluster B (5 student groups)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Analysis</strong></td>
<td>Information on comfort, occupation and heating of spaces</td>
<td>Nuanced and dynamic maps + some students mapped properties of the building (e.g. heating systems, structures, ventilation)</td>
</tr>
<tr>
<td>Development of static and limited amount of maps</td>
<td>Use of mapping method for processing and visualization of information on living pattern</td>
<td>Use of mapping method for processing, visualization and analysis of seasonal living pattern</td>
</tr>
<tr>
<td>Focus on analysis of built environment, design requirements on building skin and systems</td>
<td>Both analysis of residents and building, design requirements on skin, space plan and structure + introducing flexibility and adaptability</td>
<td></td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td>All multi-unit concepts</td>
<td>Mix of multi-unit and greenhouse concept</td>
</tr>
<tr>
<td>One group included an additional measure to respond to dynamic residents (flexible room)</td>
<td>All groups applied measures which respond to dynamic residents (dynamic heating, flexible room or thermal zoning)</td>
<td></td>
</tr>
</tbody>
</table>

It is further concluded that the analysis of the seasonal living pattern of dynamic residents is an important aspect to gain insights on the influence of the occupant behaviour on the energy demand. Overall, it was challenging for students to visualize relevant information on residents’ living pattern and correctly interpret the resulting maps in view of energy-efficiency. However, it is clear that the transition from analysis to design is a crucial part within the aim for resource-efficiency by means of a user-centred approach. In general, the analysis of dynamic properties of residents and implementation of these findings in the design phase appears difficult for students. The ability to relate user practices to energy efficiency created a barrier for many students. From this point in the design process, many students shifted from a user-centred to an object-centred approach on energy-efficient building. Moreover, the paper concludes that it is challenging for all groups of students (A and B) to create a synergy between the dynamic design and constructive design as both designs are mostly developed separately.

Further research on how to consider the influence in design of the heating and occupation of rooms on the actual energy demand is necessary. The study suggests that the development of a modified analysis tool, to interpret interviews and maps, can guide designers when applying a user-centred approach for resource-efficient building. Future research will be conducted on the underlying design methodology of the user-centred approach which enables a dynamic way of living throughout the seasons.
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