

etrofitting with

AIM-ES

(Architectural Industrialised Multifunctional Envelope systems)







Retrofitting with AIM-ES

Guidelines for using Architectural Industrialised Multifunctional Envelope systems

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Summary

The evolution of industrial processes and modern computer-commanded machinery offers innovative techniques for the retrofitting of building envelopes: Architectural Industrialised Multifunctional Envelope Systems (AIMES). The old building is 'wrapped' with a new envelope made of large prefabricated elements, mounted on top of the existing walls. By doing so, the on-site operations are shortened and occupants suffer from less nuisance and can keep usage of most of their living space. The technique also allows to extend the volume of the building, enabling interesting perspective from an architectural point of view. Moreover, the integration of building services in the core or on the exterior of the new envelope (e.g. HVAC ducts and systems, solar technologies, sun blinds) opens the way to a more holistic approach of retrofitting, with so-called 'multifunctional' façade elements. The 'holistic' feature is also to be found in a new in-depth interaction between actors, ensuring an improved quality in terms of environmental quality, energy efficiency, and indoor comfort.

This document presents the AIMES approach for retrofitting mainly using timber-based systems: the various phases of a typical renovation project are analysed highlighting innovative aspects, potential benefits, and risks associated with this new technique. Case studies and research projects from Europe are used to illustrate this guide.

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Acronyms

AIMES Architectural Industrialised Multifunctional Envelope systems

AHU Air Handling Unit
AC Alternating Current
CAD Computer Aided Design

CAM Computer Aided Manufacturing
CNC Computer Numeric Control

DC Direct Current
DHW Domestic Hot Water

EPBD Energy Performance of Buildings Directive
 ETICS External Thermal Insulation Composite Systems
 HVAC Heating, Ventilation and Air-Conditioning

Line Of Sight MP Mega Pixels

RGB Red/Green/Blue colour space

SFM Structure from Motion

Scale Invariant Feature Transform

TES Timber-Elements Systems

TIN Technical Information Note (from the BBRI)

TLS Terrestrial Laser Scanner

TOF Time Of Flight

TPS Terrestrial Point Scanner
UAV Unmanned Aerial Vehicle
VIP Vacuum insulated panel

Foreword

The evolution of industrial processes and machinery offers innovative techniques for the retrofitting of building envelopes. Prefabricated envelope modules can now be assembled off-site and subsequently attached to the existing structure of a building, providing an accelerated on-site phase with enhanced quality and many architectural possibilities. Under certain conditions, the old building is easily 'wrapped' with a new skin on top of the existing walls, avoiding therefore large disturbances for the neighbourhood and the occupants who can keep the usage of most of their living space (Figure 1). The extension of the building volume is also easily achievable, enabling interesting architectural perspectives (Figure 2). Finally, the integration of building services on the surface or in the core of the new envelope (e.g. HVAC ducts and systems, solar technologies, sun blinds) opens the way to a more holistic approach of retrofitting, with so-called 'multifunctional' façade elements. The 'holistic' feature is also to be found in a new thorough interaction between actors, ensuring an improved quality in terms of environmental performance, energy efficiency, and indoor comfort. Associated with these modern standards in the retrofitting process, the involvement of occupants and owners has become crucial to ensure an optimal match between the design choice and final users' wills/needs, in the perspective of improving the 'quality of life'. In summary, the insulated prefabricated façade systems studied here combine the following properties:

Can be installed on top of existing walls

- Can be produced in the form of large panels
- Allow much architectural freedom:
 - Adaptability to various types of buildings
 - Multiple choices for the external finishing layer
 - Possibilities of using prefabricated façade components for the extension of building volumes
- Allow the integration of windows and/or various building services

From this point, systems combining these properties will be referred to as **Architectural Industrialised Multifunctional Envelope Systems** (AIMES) in this document. A single AIMES façade part will be referred to as an AIMES module or an AIMES element.

AIMES modules can be designed in many ways, the key parameters being their structural composition, their size, their level of prefabrication, the characteristics of the interface between the new and the old envelope, and level of technicality. The last parameter is linked to the possibility of integrating building services technologies inside or on top of the new envelope. Generally, due to the cost implied by a heavier conception and investigation phases compared to traditional refurbishment methods, such industrialised envelope

AIM-ES Project

The AIM-ES project is part of BRUSSELS RETROFIT XL, a multidisciplinary platform that brings together thirteen Brussels research teams with different expertise in the context of renovation and provides them with the opportunity to valorise their research results. In total eleven projects focus on various retrofitting aspects relevant to the Brussels housing market.



Figure 1. Principle of prefabricated envelope modules projected on an existing building

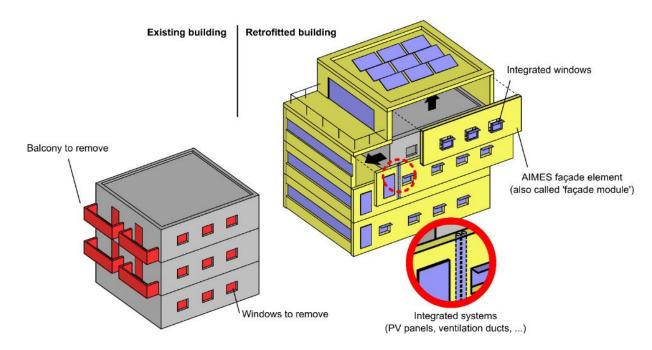


Figure 2. Principle of the AIMES retrofitting technique

systems are more suited for the rehabilitation of large buildings or ensembles of buildings showing a repetitive architecture, as is for instance often the case with social housing complexes.

During the last decades, tens of building were renovated throughout Europe with AIMES elements. In parallel, some pioneering research projects initiated the scientific contextualisation of these innovative techniques by compiling the know-how. In 2011, both the *IEA Annex 50* and *TES EnergyFacade¹* projects proposed reference documents (see V). Much information related to prefabricated envelope systems for retrofitting is already available in literature, in the forms of project reports, scientific papers or technical documentation. Several – mainly wood-based – module systems already proved their great potential (fast on-site execution, high-quality construction, cost-effective, reliable, etc.), but are not widespread nor well-known, certainly not in Belgium. Such innovative technique, however, could help to stimulate the renovation initiatives in Belgium. This document wants to resolve this problem by providing guidelines addressing the actors of the retrofitting sector so that pilot projects can be encouraged in Belgium. In that context, the essential information is summarised here, with a focus on critical design and decisions parameters, and without too much redundancy (where possible these guidelines refer to existing reference documents).

II. Systems studied in the document

As mentioned before, much freedom exists when designing AIMES elements. Several research and commercial systems were developed in Europe and are well documented in literature. Large-size timber-framed modules (Figure 3) respect the AIMES definition criteria and are relevant for a quick spreading of prefabrication in retrofitting applications. They rely on simple construction techniques that many companies master in Belgium. Their light weight allows to easily extend the building volume without requiring complex tasks within the design or for the implementation.

¹ TES stands for 'Timber based Element system'

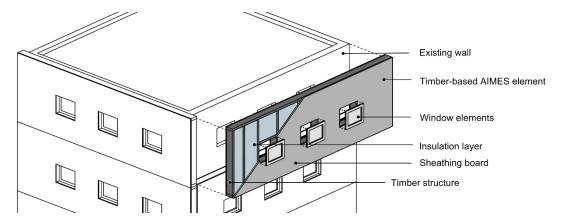


Figure 3. Principle of large-size timber-based envelope system applied on an existing wall (horizontal layout illustrated, without finishing layers)

Moreover, the interactions between the project actors will be greatly facilitated when the design considerations are not completely new. A large number of existing case studies can also support the design process. The focus in this guidelines document is put on timber-based elements. However, it should be mentioned that more ground breaking possibilities exist or are in development (e.g. based on a concrete or steel structure, in the form of composite panels, etc.). Yet, scientific and experimental feedback was needed to redact the present manual, which explains the choice for the family of timber-based systems.

For the timber-based system family, the *TES-Energy Façade* project provides much technical information [1]. **Only TES systems** that are applied on top of the existing walls will be discussed here, possibly with removal of some old layers which are not structural. More precisely, two particular 'types' of TES façade modules are ultimately retained for further analyses, namely the closed type and the open type:

- The first type (**Figure 4**) is closed on both of its sides with sheathing boards and the main insulation layer of the module is almost always implemented in the factory (off-site). A separate 'adaptation layer' is necessary to fill the void space between the new envelope and the existing wall.
- An open TES system (Figure 5) has no sheathing board on the rear side of the module (i.e. the side facing the existing wall). After the fixation of such 'empty' panels on the existing envelope, the insulation is injected via holes, which are pre-drilled off-site. The blown-in insulation also plays the role of adaptation to the existing envelope.

(The different design solutions are described in detail in **section 3.3.1** of the document)



Figure 4. Terraced houses retrofitted with a closed TES system (<u>Roosendaal, NL</u>)

(top) Houses before the retrofit (bottom) AIMES element



Figure 5. An apartment block retrofitted with an open TES system (Berlin, DE)

III. Exemplary cases

Many projects were achieved in Europe during the last years and proved the efficiency and adaptability of the different AIMES types. In order to provide real-life examples and adequate technical solutions in relation with the building properties, this guidelines document is constantly referring to some 'exemplary cases'. In other terms, achieved projects will allow to draw perspectives concerning the 'dos and don'ts' both in terms of design and on-site execution.

In an ultimate step, twelve European case studies were selected to support the guideline recommendations upon three sampling criteria. First, the final sample of cases had to reflect the diversity of buildings which are concerned by retrofitting with AIMES elements in an economically viable way. Secondly, the open and closed façade module construction had to be well-represented (see 3.3.1), with façade modules installed on top of the existing walls. Among similar projects, the priority was given to those with a high level of available technical information (detailed plans and details, HVAC services, types of infrastructure used during modules fixing, etc.). A detailed description of the different cases is provided in the Annex of the document. In the text, reference to case studies is indicated by underlined text.



The present guideline is organised around each phase of the 'ideal representation' of a retrofit project (Figure 6):

- The pre-project phase extends from the project initiation, with the definition of clear objectives meeting the wishes of the owner, to the planning of the project with organisation of the subsequent phases. A first feasibility study will determine
 - whether the use of industrialised façade modules is relevant, based on a basic building survey.
- The pre-construction phase contains the investigation and design stages. These two stages are indivisible as an in-depth building study is crucial to determine the design constraints. During the design stage, the technical choices are analysed in the light of the identified constraints.
- The **construction phase** contains the off-site and on-site stages. The off-site operations cover the module prefabrication based on a production model. The on-site stage covers all actions related to the site preparation and to the interventions around and on the building.
- The post-construction phase groups the preventive and corrective tasks that follow the actual interventions on the building and ensures that the building eventually complies with the planned performance.











Figure 6. Illustration of the different stages of a project, from surveying to construction. Source: [1]

Throughout this document, for each task linked to a particular phase of the project, the various primarily concerned actors will be mentioned in a summary table. The latter also provides relevant questions to be asked when performing the concerned task. Of course, the reality can be much more complex as several roles can be endorsed by the same actor (the AIMES designer can also be in charge with their production and, more generally, a strong interaction exists between the design and building teams) or several actors can intervene in the same tasks. In addition, the project team is always scaled to suit the complexity and size of the project. In a similar way, all tasks and concomitant questions are not systematically relevant considering the specificity of each (e.g. previous refurbishments, constraints interventions). Finally, in order to illustrate the transfer of information between tasks, the main data inputs/outputs with regard to each task are also indicated. Figure 7 illustrates suchlike summary table.

The document was conceived to provide a general insight concerning the whole retrofitting process using prefabricated façade elements. However, since a lot of well-structured information can already be found in literature, the accent was put on some key project phases inside the AIMES guidelines, with adaptation to the context of Belgium and reference to achieved cases in Europe. In this respect, the connections between building investigation and façade module design/implementation phases were extensively studied and the available information was processed and completed. The other phases are more briefly described in the document.

Table 1. Key project actors

Owner(s) and owners representative(s)
Building operator(s)
Tenant(s)
Local public authorities
Architect(s)
Design/engineering office
Energy & EPBD
HVAC & Building services
Stability
Building Physics
Fire safety
Land surveyor

Various consultants/experts Diagnostics Heritage values

AIMES designer (if different from architect)
AIMES producer (timber frame manufacturer)
General contractor & subconstractors

Relevant actor(s):

" ...

Relevant questions:

" ...

Useful information:

Inputs

Output information:

MAIN OUTPUTS

Figure 7. Example of a summary table for a specific task

Prefabrication entails a faster speed of on-site execution compared to traditional insulation solutions for retrofitting (e.g. ETICS), in exchange for a lower assembly tolerance. It explains why the building should be known precisely from the standpoints of both its original design and current state. The various surveys constituting the building investigation phase define some constraints that will preferentially orient the designer towards specific technical solutions. The 'repertoire' of solutions is thus analysed in the document in the light of the investigation phase with experience feedback from European case studies. **Design aspects relative to Building Physics are not left behind** and are treated in an independent chapter.

In turn, the façade module design clearly orients the on-site interventions as well as the site management. For example, the choices in terms of equipment incorporated in façade modules (e.g. decentralised ventilation units) can cause additional on-site interventions (e.g. holes for ducts in the existing walls). In the section dedicated to the on-site phase, the document presents all possible interventions with connections to aspects of module design. Again, the chosen European cases allow the further development of the guidelines by providing the necessary feedback and delivering examples of implementation choices. When necessary, the possible adaptations to comply with Belgian standards are mentioned.

Figure 8 illustrates the structure of the document, indicating the links between the different chapters.

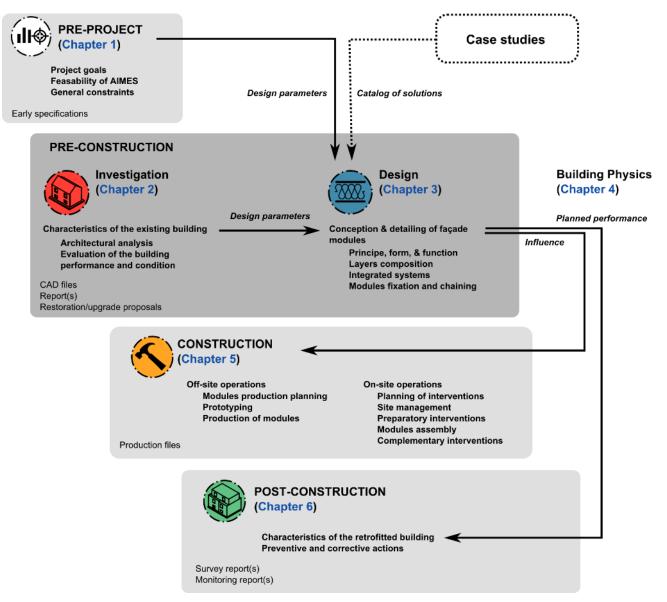


Figure 8. Contents of the document and specific attention points organised around an 'ideal' retrofit project

V. Useful literature

Research projects and associated documents

Name	IEA Annex 50				
Period	2007-2011				
Website	http://www.ecbcs.org/annexes/annex50.htm (last visit: 06/06/2016)				
Framework & partners involved	European project within International Energy Agency building research & development program Countries involved: Austria, Belgium, Czech R., France, Netherlands, Portugal, Sweden, Switzerland				
Summary	The objectives of this Annex was the development and demonstration of an innovative whole building renovation concept for typical apartment buildings based on prototype, prefabricated envelope systems with integrated building services systems. The project has been structured according to the following five research areas:				
	Concept definition and specification/ Integrated roof systems/ HVAC and solar systems/ Façade elements/ Monitoring and dissemination. (Adapted from http://www.ecbcs.org/annexes/annex50.htm)				
Key points	 Good starting point to understand the challenge of AIMES retrofitting 4 systems studied Some demonstration buildings monitored 				
 A building retrofit strategies guide: typical solutions for whole building renovations A retrofit module design guide: guidelines for system evaluation, design, construction and quassurance A report on case studies A 'Retrofit Advisor' tool 					
Case studies	 6 case studies in total 3 cases are included in this document: Roosendaal (NL), Graz-1 (AT), Zürich (CH) 				

Name	TES EnergyFacade
Period	2008-2010
Website	http://www.tesenergyfacade.com/ (last visit: 06/06/2016)
Framework &	European research project funded by the Woodwisdom.Net
partners involved	Countries involved: Finland, Germany & Norway
Summary	'TES EnergyFaçade' is presented as a prefabricated building system based on large-size timber frame elements that introduces the benefits of modern timber construction to the modernisation process of the existing building stock. The result of this project is a manual as a fundamental basis for the optimisation of the building envelope through TES approach.
Key points	 Based on large-size, timber-based elements The goal was to develop a façade renovation method The 'TES manual' is a crucial reference used all along this document
Documents	 1 manual presenting the TES method: cover investigation, design, construction and quality assurance aspects
Case studies	 3 case studies in total 1 case is included in this document: <u>Buchloe (DE)</u>

Name	smartTES		
Period	2010-2013		
Website	http://www.tesenergyfacade.com/ (last visit: 06/06/2016)		
Framework & partners involved	European research project funded by the Woodwisdom.Net Countries involved: Austria, Finland, Germany & Norway		
smartTES emerged from the preceding research project TES EnergyFacade and grounded on the method. The main objective of smartTES is to advance the sustainable method of energy efficient building retrofit through the development of a multifunctional building envelope. (Adapted from http://www.tesenergyfacade.com/)			
8 work packages: Multifunctional TES/ TES extensions/ TES Urban renewal / TES Market Acce Sustainability / Climate adaptation of buildings + Coordination • Reference research project on the 'multifunctional' aspect of AIMES elements			
Documents	 6 reference books Innovation and marketing/ TES extensions/ Multifunctional TES/ Building Physics/ Fire safety/ Sustainability 		

Name	E2Rebuild				
Period	2011-2014				
Website	http://www.e2rebuild.eu/ (last visit: 06/06/2016)				
Framework &	European project (7th framework program)				
partners involved	Countries involved: Austria, Finland, France, Germany, Netherlands, Sweden, United Kingdom				
Summary	The aim of this project was to speed up the development towards an energy efficient construction and building sector by (1) investigating, promoting and demonstrating cost effective and advanced energy efficient retrofit strategies; (2) Establishing and demonstrating sustainable renovation solutions that will reduce the energy use; (3) Creating a holistic industrialised process that aims to minimise technical and social disturbance for tenants and facilitates energy efficient operation and use of the buildings including encouraging energy efficient behaviour. (Adapted from http://www.e2rebuild.eu/)				
 Highly detailed case studies Reference research project on collaborations models and the integration of occupants behaviour into AIMES design 					
Documents	 4 guidelines: (1) to survey operations required for façade prefabrication; (2) to off-site production, on-site assembly and logistics; (3) to end-users; (4) to operators A document reviewing various collaboration models from the case studies 				
Case studies	 7 case studies in total 3 cases are included in this document: Augsburg (DE), London (UK), Oulu (FIN), Roosendaal (NL) 				

Other interesting research projects

- European project MEEFS (Multifunctional Energy Efficient Façade System for building retrofitting)
 - Still ongoing.
 - The development, evaluation and demonstration of an innovative multifunctional façade system based on a highly innovative and modular approach.
 - Website: http://www.meefs-retrofitting.eu/
- European project SQUARE (A System for Quality Assurance when Retrofitting existing buildings to Energy efficient buildings)
 - 0 2007-2010
 - Development of a quality assurance (QA) system for retrofitting and maintenance, adapted to conditions in several European countries and implemented in pilot projects
 - Website: https://ec.europa.eu/energy/intelligent/projects/en/projects/square

Other useful documents

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1. Pre-Project phase

1.1 Chapter summary

This first chapter (Figure 9) emphasises on how to:

- Determine the exact needs linked to the building transformation
- Provide a preliminary validation for the applicability of the AIMES solution

Obviously, the current state of the building has to be summarily evaluated during the pre-project phase and a good balance has to be found between expected improvements on the environmental, technical, organisational and architectural points of view and the direct retrofitting costs.



What are the project goals and how can it be assessed if the AIMES approach is relevant?

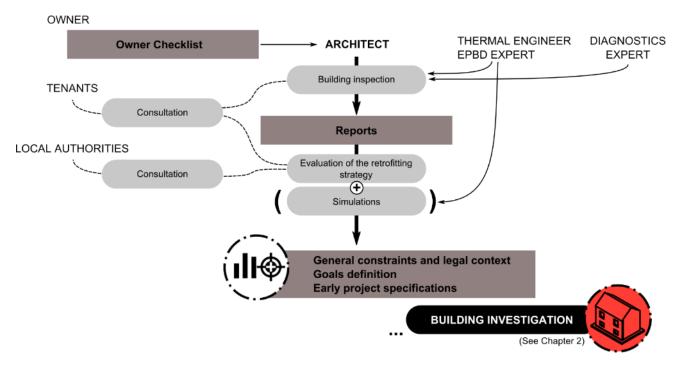


Figure 9. Diagram of actions during the pre-project phase

1.2 Initiating factors

The renovation initiative generally originates from the owner, whether it is a single individual, a corporation, or some public authorities. There exist **several possible reasons to initiate an extensive retrofitting** of the building envelope (that can overlap):

There is a change in the building use



- The building does not meet the expectations in terms of general quality and comfort (excessive deterioration of the façade and/or roof, low comfort, etc.). Occupants will generally communicate their dissatisfaction to the owner and imply daily or seasonal problems they are experiencing
- The building does not meet the expectations in term of its energy performance
- ...

In the current economical context, the owner will benefit from the generally choose to structural/aesthetical renovation to enhance the energy efficiency and indoor comfort of the building. The root of the retrofitting process could also be the energy performance improvement in itself, even if the structure of the building does not present substantial damage. The underlying reason can be economic and linked to the high energy price (in which case the user is often at the root of the retrofitting desire) or legal, as the legal framework for building energy performance is evolving very quickly. Some specific incentives can also be the kick starter to this will.

Classically, the first step is for the owner(s) and building operator(s) to **set a list of key objectives** that should be met. In other terms, he should provide a clear overview of the **desired end-state** of the building after retrofitting. It can include window replacements, façade insulation, balcony replacement, ground plan modification, etc. It is crucial to **involve the occupants** in this early setting of

(1.2) Relevant actor(s):

- Architect
- Building operator
- Owner
- Occupants
- (Local public authorities)

Relevant question(s):

- Who is the owner of the building?
- What are the causes of the retrofitting process?
- What is to be improved according to occupants?
- Is there any recurring complaints from occupants?
- Was there any legal obligation to retrofit?
- Are there any incentives to retrofit?
- At first glance, which building element needs replacement, modification or suppression?
- Does any element of the building needs to be preserved?
- Is there any modification planned in terms of protected volume?

Output information:

 BUILDING OWNER OBJECTIVES CHECKLIST



Figure 10. Some apartments in <u>London (UK)</u> before the retrofit, characterised by an outdated conception & thermal issues

objectives. As users of the building, they are the only ones able to highlight some problems that are not directly visible (e.g. acoustic problems, low comfort at some point of the day or of the year). The **improvement of their 'quality of life'** should always stay in the mind of the building operator.

Once general retrofit objectives have been outlined, the owner of the building has to communicate them to a specialist who holds the knowledge and technical competences to carry out and supervise the project. In Belgium, it is a legal obligation to hire an architect when the renovation: (1) relates to structural aspects; (2) relates to a change in exterior appearance; (3) modifies the use, destination or number of apartments in a building. Given the extent of the transformation associated to the AIMES approach, an architect will always be imperative during the different project phases.

Once the project team is designated, specialised experts able to support the project should be identified as soon as possible. In some cases, the owner holds the expertise necessary to lead the initiation phase (company or legal institution with permanent architects) but a designated architect will still be obligatory once the project team is formed.



1.3 Primary building inspection

A set of building parameters has to be compiled and analysed with the objective of **providing a general 'picture' of the building**, including its structure, use, and current/potential value on the market. Such information may in turn help in the determination of a **preliminary retrofitting strategy** which is the most suitable to meet the objectives fixed by the building operator. If all data is not immediately available, it should be gathered with simple survey or measurement methods which are described in the following subsections.

1.3.1 Draw a general typological profile

This step aims to compile a document that provides a general picture of the building, allowing it to be **classified amongst typical buildings of the region**. It summarises the general information concerning the building such as:

- Type of construction (Figure 11)
- Year of construction
- Year of previous renovation
- Location/environment
- General volumetry / shape of the building
- Type and number of stories
- Outer dimensions
- Number of living units
- Typical living unit size
- Type and number of main accesses
- Type and number of balconies / terraces
- **'** ...

(1.3) Relevant actor(s):

See subtasks

Relevant question(s):

• What is the type, quality and general condition of the existing building and its structure?

Output information:

BUILDING INSPECTION REPORT

(1.3.1)

Relevant actor(s):

- Architect
- Owner

Relevant question(s):

- What are the main characteristics of the building?
- What are the characteristics of the living units?
- What is the general 'typology' of the building and how is it integrated in its environment?
- ...

Sometimes, typological tools are useful to categorise a building from a particular geographic area on the basis of several relevant parameters. The parameters set can be limited (e.g. year of construction and type of construction) or detailed (inventory of building components such as balconies, windows, systems ...). At this stage general classification systems are sufficient. A useful European national building typologies web tool was

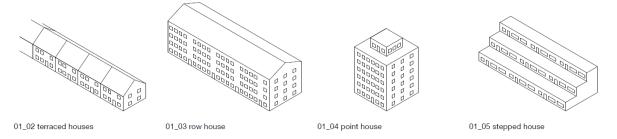


Figure 11. Excerpt of some examples of construction types. Source: [1]



developed within the *TABULA* project [2] (**Figure 12**), wherein a simple typology for buildings in Belgium is described (**Figure 13**). For Switzerland, the Lucerne University provided an example of a detailed typology in the context of prefabricated modules retrofitting, developed in collaboration with *IEA Annex 50* [3]. General building types are there defined on the basis of 3 parameters: the position in construction, the number of stories and the period of construction.

The AIMES method is clearly not adapted to all types of building and the typological analysis of a particular building provides a first basis for the discussions related to the retrofit options. For example, a building in a dense urban context may often lack the required accessibility for bringing large AIMES elements (see 2.2.3). On the side of local authorities, typological analyses on a building stock may provide a strong tool for policy making. Indeed, it can provide an overview of the existing buildings types and support the development of retrofit strategies at city or municipality scale.

Tabula Web Tool

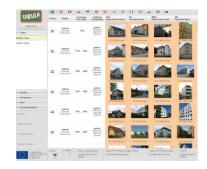


Figure 12. Web Tool for European national building typologies. Source: [2]



Figure 13. Excerpt of general building types according to the Tabula Web Tool. Source: [2]

1.3.2 Identification of heritage values and other conservation restrictions

Any cultural or historical value of the edifice should be identified. For this, actors specialised in Heritage Architecture might intervene. The archaeological value of the site should also be known. In the event of a listed status of the site or the building, the retrofit process will have to meet special requirements that are imposed by legal measures. In some cases, there is no actual legal restrictions, but the local authorities can impose some limitations within the possible interventions. The AIMES solution has a strong impact on the exterior aspect of the building, and it is barely conceivable that it would provide a good solution for buildings of which the façade is listed. Nevertheless, in some

(1.3.2) Relevant actor(s):

- Architect
- Local public authorities
- (Experts: Heritage value)

Relevant question(s):

- What are the general constraints due to the architectural value of the building or the archeological status of its implementation site?
- Is there any legal protection status attached to the building?
- Even without protection status, is there any extra-legal context that can impose constraints or delays in the interventions?



specific cases (e.g. a protected view) it is possible to combine the AIMES solution for the non-listed façades with a more traditional approach for the listed façades.

1.3.3 Inspection of the condition

This phase targets the examination of the current condition of the building. It allows to summarily evaluate the amount of interventions that should be considered among which some might not have been planned by the project owner. The objective is to obtain a **general impression** of the building as it stands. The gathered information will serve as a **preliminary framework** for the building renovation. At this stage, it is not expected to lead a detailed survey which will only be performed later (see **2.3**). In some cases, some elements of the general diagnosis can already be found in the owner's objectives checklist.

The **energy efficiency** of a building is particularly important to judge its quality among the existing stock. The first step of the general inspection is to provide all the relevant information with respect to this aspect:

(1.3.3)

Relevant actor(s):

- Architect
- Occupants
- (Experts: Building Physics / EPBD / stability / ...)

Relevant question(s):

- What is the general condition of the building?
- Which general assessment concerning its energy performance can be made? (based on simple investigation methods)
- What is the amount of work to enhance its attractiveness on the market?
- List the previous interventions for energetic reasons (complete/partial renovations)
- Establish the annual consumption with respect to typical values for similar buildings
- Briefly characterise the building structure and envelope
- Characterise the HVAC systems
- Perform some measurements (indoor conditions, thermography, blower door test, ...)
- Survey the occupants of the building

The second step of the general inspection is formed by the brief evaluation of the **condition** of the building and its systems:

- Evaluate the general condition of the structure, the roof, the façade, the windows, etc.
- Find evidence of pathologies:
 - Structural problems (e.g. cracks, deformation)
 - Moisture problems (e.g. rising damp, mould)
 - Salts efflorescence
 - o ..
- Evaluate the technological relevance of HVAC systems (including the situation in their life-cycle)
- ...

Finally, the **quality of individual dwelling units** can be examined with reference to today's living standards (e.g. size of units, equipment, lighting conditions, moisture problems, acoustical insulation between units and from the outside). In this stage the involvement of occupants is particularly precious and allows to save time.

The information necessary to establish the primary inspection report can be gathered from **different sources** such as archive drawings, official documents, photographs, interviews or visual ascertainment. It should be mentioned that various **indexes** can also be used to assess the quality of the building within the building stock and to foresee the prioritised interventions. The reader may find the description of such indexes for Wallonia in [4]. These evaluation systems are elaborated with considerations to modern requirements in terms of



comfort, energy consumption and environmental performance. The combination of the typological traits of the building with an evaluation of its quality provides crucial information for estimating the relevance of AIMES approach, an asset for policy makers.

1.3.4 Involving the occupants in the target definition

People who live in the building should always be included early in the decision process. First, whereas they may not have a clear understanding of the problems relative to the existing envelope and systems, they can clearly **help the architect to identify symptoms of these problems.** Indeed, it is impossible to list all the defects of the building by a simple visit. The first clear reason lies in the fact that many weaknesses are season-dependent (e.g. overheating problems, condensation). **Well-thought interviews or surveys** may orient the retrofit approach. In addition, a good communication ensures that future occupants accept the design choices and participate in their elaboration. **The early acceptance**

(1.3.4)

Relevant actor(s):

- Architect
- Occupants
- (Experts: Communication / Diagnostics)

Relevant question(s):

- How do the occupants see their living environment?
- How do they feel about the building being retrofitted?
- According to them, what should be remediated?
- Which surveying method could be easily implemented to answer these questions?

and appropriation of the project is also crucial. In that respect, more than only current and/or future occupants, the neighbours should also be consulted. In fact, the acceptance should be ensured for all the people whose living surroundings will be impacted. Finally, modern low-energy retrofits are based on technological systems that are ultimately applied by users. There is an underlying learning process that has to be dealt with. Involving occupants in the early phase of the planning process raises the likelihood for a successful appropriation and understanding of technical upgrades. Many clear examples of interaction between professionals and occupants can be found in [5],[6] and [7]. Well-thought communication patterns are not to be undervalued in order to assure a quick and smooth retrofitting process.

1.4 Evaluation of the AIMES retrofitting strategy

AIMES modules can be a good solution for retrofitting the façades. They offer controlled quality standards in a high energy performance perspective, they are independent of weather conditions to a large extend), and occupants often can stay in the building during the construction phase. However, various requirements have to be met so that this solution can be judged as adequate and economically viable.

The building owner has to acknowledge a general renovation strategy, elaborated by the architect, who will analyse the pertinence of prefabricated envelope elements in the light of five main angles of study: (1) the legal and contextual parameters related to retrofitting; (2) the economic and environmental parameters; (3) the technical parameters; (4) the organisational parameters; and (5) the socio-cultural parameters. These points are explained in the next sections.

(1.4) Relevant actor(s):

- Architect
- Building operator
- Occupants
- Owner
- (Experts: Building Physics / EPBD / stability /finance / ...)

Relevant question(s):

- Is the prefabricated modules approach adapted?
- What are the benefits of a retrofitting with prefabricated modules?
- Is a combination of techniques more suited to the retrofit?
- If prefabricated modules are used, what is the best level of prefabrication?

Useful information:

- BO OBJECTIVES CHECKLIST
- BUILDING INSPECTION REPORT



1.4.1 Relevant parameters for assessing the retrofit strategy

(a) Legal and contextual parameters

These parameters cover any **constraint imposed by the legal framework and the contextual situation**. It includes restrictions in the possible interventions linked to the architectural value of the building or the archaeological value of the site, as well as standard city code restrictions. The type of building and its future usage can also impose additional legal or contextual restrictions. When prefabricated façade elements are involved and no specific 'patrimonial value' can be attributed to the existing building, the main attention points in a legal point of view will often lie in the **expansion of the dimensions** of the building and its **appearance**. Regarding to the latter, it should be mentioned that there exists a large freedom of design with AIMES solution, which offers a large panel of aesthetical solutions. The expansion of the thickness of walls is unavoidable and can be inadequate in a dense urban context. The availability of local expertise for application of AIMES technique can be another major 'contextual' drawback as it requires some specific competence (e.g. manipulating large elements during the mounting phase) and machinery (e.g. a production chain for large façade elements allowing a high prefabrication level). On the contrary, if this expertise can be found in a local contractor, specific incentives related to innovation or green buildings should be identified as they can help the financial viability of the project (see 'Economic and environmental parameters' below).

(b) Economic and environmental parameters

The basis of the economic projection is the **comparison between the building state and the market potential** as summarily described in *IEA Annex 50* [8]. The market potential analysis provides an insight on the added value that can be obtained through the retrofit process and thus the viability of each type of retrofit approach given the required initial investment. Regarding specific advantages of an improved energy performance, the distinction must be made between the owners who actually use the building and the ones who do not. In the first case and in the owner point of view, the improved energy efficiency will result in a reduced cost of use and an easily calculable return-on-investment. For the second case, the attractiveness of the building can constitute an important economic parameter for the owner, as the occupants will benefit from increased comfort and reduced energy bills. Specific goals (and associated criteria) related to the **general environmental quality** of the project (e.g. waste and water management, health of occupants) should also be put on paper. In that respect, various **incentives** (e.g. 'exemplary' buildings) could potentially be obtained and their requirements should be rigorously analysed in the light of the performance offered by AIMES.

Retrofitting with prefabricated façade elements is certainly not the cheapest solution when lots of building services are planned to be integrated in the new envelope modules. However, the initial higher investment can be compensated by the quality of the retrofit, the cost control, and the attractiveness of the high standards eventually achieved. Regarding higher design costs, one will always benefit from the scale factor if the study costs attached to prefabrication can be dampened by the geometrical repeatability within the building or the existence of multiple similar buildings. The higher cost of design should also be put in perspective with the strong impact of AIMES on the execution phase and its associated costs. A higher quality control and a quicker mounting phase can result in a reduction of the execution budget through limitation of on-site adjustments, possible reduction of the contractor expenditure (renting of machines, installation of scaffolds, ...), and a faster recovery of economic activities bond to the building (if such exist). When comparing the execution costs to more traditional retrofitting techniques, these points must be studied with care.



(c) Technical parameters

In terms of technical parameters, AIMES offer great perspectives for integrating building services and transforming the existing volume with vertical or horizontal extensions. The latter includes a possible integration of existing balconies in the heated space. It is therefore possible to intervene at the compactness of the building.

The improvement of the building should both be considered in the light of the owner's checklist and of the characteristics of the existing building. Indeed, the main technical obstacles in the implementation of AIMES lie in a poor appropriateness of the technique given the original characteristics of the existing edifice. From an architectural point of view, the building preferably shows a certain amount of repeatability to allow the viability of a prefabrication approach. Similarly, the geometry of the building should not present a complex shape or a random distribution of architectural features (windows, balconies ...) or else the task of the AIMES designer could be significantly hindered. Even if prefabricated panels could theoretically adapt to complex façades, it is generally not economically viable. Analysing results from the building inspection, it should also be stated if the existing structure is in a condition that allows the fixation of the new façade elements, without implying the need for heavy restoration, reinforcement, or new foundations. By the same token, the hygrothermal behaviour of the envelope and existing moisture problems should be well understood to judge the applicability of AIMES.

The required equipment for mounting the new façade modules can often be limited to mobile cranes and elevator platforms. **Scaffolding can generally be avoided**. This is one of the technical advantages of AIMES for the execution phase. In addition, a well-planned design can enhance the general quality of the retrofit, compared to more traditional approaches.

(d) Socio-cultural parameters

For the project team, the particular collaboration model associated with AIMES requires some familiarity with **high interaction processes**. A lack of (clear) communication will hinder the success of the project because of the high speed of the execution phase, and a lower tolerance of the assembly.

During the execution, AIMES solution reduces the nuisances for occupants whose social activities are less impacted and for a reduced time. Because the **perception of the building identity** is crucial, it should be ensured that the changes made are compatible with this perception. Nonetheless, with a good communication scheme which considers the will and needs of the occupants/owners, and given the freedom that exists in AIMES design, a good appropriateness is achievable.

The building retrofit should also integrate the social habits of the final users. Whereas façade modules have by themselves a low impact on these habits, new incorporated devices (e.g. automatic blinds, decentralised ventilation units) or modifications in the spatial organisation can have more effect. However, there exists a real chance of improving the 'quality of life' of occupants, and this opportunity should be seized, especially by considering advantages of modern techniques and systems that can be incorporated in AIMES.

(e) Organisational parameters

The choice of a retrofit strategy also covers a wide variety of organisational parameters. Related to the project organisation, the different teams involved in the project need to interact together more deeply than with a traditional approach. It means properly assigning the different tasks, with regular follow-up and/or control



steps, within an elaborated 'lean' strategy. Moreover, the transfer of information needs to be thoughtfully organised to guarantee an efficient work, possibly integrating modern BIM approaches.

AIMES offers a reduced execution phase. However, this shorter time window and the size of façade panels require a **good planning of the sequences of interventions**. Often, the occupants can keep use of most of their living space during the works even if some specific measures should be undertaken to ensure their satisfaction during operations.

After the retrofit, the project team should plan a familiarisation phase of the occupants, especially if the building services were renewed during the process. Maintenance operations should also be planned, possibly involving occupants or building operators.

(f) Diagram

The diagram presented in **Figure 14** summarises the main parameters that intervene in the definition of a preliminary retrofit strategy. These parameters are classified according to 4 main categories:

- The project
- The existing building
- The execution
- The retrofitted building

Potential benefits of AIMES⚠ Specific attention point with AIMES







	Project parameters	Before	Execution	After
Legal Contextual	Restrictions linked to urban code A Restrictions linked to historical value Restriction linked to archeological value Existing incentives Expertise available locally A	Nature and usage of building Historical Value Archeological value	Consequence of operations on traffic	Use building as 'demonstrator'
Economic Environmental	Budget Planned return on investment Incentives with achievable goals	General condition of the building Market value "Repeatability" of building features 1	Costs linked to on-site operations Costs linked to on-site adjustments Costs linked to economic activities Costs linked to the building	Global environmental quality Market value / Attractiveness DEnergy cost DENERGY Standards (comfort, safety, space,)
Social Cultural	Interactions between professionals " with occupants " with neighbours "	Social habits of occupants Specific perception of the building Architecture	Impact on social activities the linked to the building Nuisances for tenants & neighbourhood the linked to the building	'Quality of life' / Satisfaction 🖒 'Acceptance' of new technologies 🛧
Technical	Goals in terms of thermal performance Extremely high thermal performance goal	High number of storeys \(\frac{\Lambda}{\text{Number}} \) Number and types of openings Large irregularities of the façade \(\frac{\Lambda}{\text{N}} \) Existing hygrothermal problems Existing problems linked to accessibility Condition of systems	Quality control 心 Required mounting equipment 心企* and infrastructure	Volumes transformations (1) Integrated solar systems (1) Integrated ventilation systems (2) Other integrated systems (2) Modalities of maintenance Accessibility for maintenance (A)
Organizational	Planning efforts Transfer of information between actors " " " to final users The state of the	Type of occupancy of dwellings	Season of execution Duration of on-site operations Need for relocation of tenants Need for amenagement of access and/or storage spaces	Familiarization with new technologies Frequence of maintenance

Figure 14. Schematic decision support chart. *This parameter is subtle: whereas the AIMES solution can remove the need for scaffolding, large lifting devices are required, which requires more space for access and manipulation



1.4.2 Feasibility study tools

Many tools and documents exist to help the planner to orient the general retrofit strategy [9]:

- ECBCS Annex 56: Reliability of Energy Efficient Building Retrofitting – Probability Assessment of Performance & Cost
- ROSH: Energy recovering refurbishment check-up for multi-family dwellings
- SQUARE Quality Assurance System
- AVASH: Energy and cost implications of different insulation, air-tightness and ventilation strategies
- E-RETROFIT-KIT: Passive House Retrofit Kit
- Smart-e Buildings: Toolbox
- Agentschap NL SenterNovem: energiebesparingsverkenner voor onderhouds- en renovatieprojecten en voor individuele woningen;
- T-zero
- EST Home Energy Check tool
- SUDEN Factor 4: Life Cycle Energy Costing tool for social owners
- EnPROVE: Software for energy consumption prediction in existing buildings
- ROSH: Audit and advice tool-kit
- ...



Figure 15. Retrofit Advisor which includes the prefabricated modules solution. Source: [10]

Within the *E2Rebuild* research project, a *'European Retrofit Advisor'* was developed. It offers to compare AIMES solutions to more conventional techniques for feasibility assessments (**Figure 15**).

It is observed that the energy aspects play often a central role in the early feasibility studies. Simple energy simulations will often help to evaluate the benefits from various scenarios in terms of energy efficiency and comfort improvement and to link these to the cost implied. In this early stage, the geometry of the building, a necessary input for the energy models, can be surveyed by simple but efficient methods such as 'Structure from Motion' (SFM) photogrammetry (see **2.2.2(a)**).

1.4.3 Project definition

Once the objectives of the retrofit are established and the viability of the AIMES technique is preliminary validated², people forming the core team of the integrated project should be gathered as soon as possible around some early specification sets. Indeed, it is essential that a designated architect surrounds himself with the proper experts in order to guarantee an optimal progress of the retrofit project with prefabricated modules. An extensive investigation phase is necessary to design the AIMES modules and multiple information paths are created between the actors. This investigation effort is a counterweight to the time gained on site compared to other retrofitting techniques. In this highly interactive context, the responsibilities of each actor should be determined clearly since the beginning of the project. It should be mentioned that many examples

² Possibly in combination with more traditional renovation techniques



of project initiations can be found in [5], which illustrates the diversity of 'collaboration models'. **Table 2** shows, as an example, the actors involved in the retrofitting of row houses in <u>Roosendaal (NL)</u> (See **Annex**).

Table 2. Key actors involved in the retrofitting of row houses in Roosendaal, NL

Role	Design	Construction	Monitoring	
Building owner	Х	X	X	
Architect	Х			
Energy specialist	Х	X	X	
Structural engineer	Х			
HVAC engineer	Х	X		
4 Contractors*		X		
University	Х		X	
*For HVAC, external façade cladding, timber manufacturer,				
and general contractor				

Following, the phases of building investigation, modules conception, production, and implementation should be planned rigorously, through a clear lean planning, in order to optimise the retrofitting process. For each actors, clear objectives, timing restrictions, responsibilities, and tasks should be delimited.

2. Pre-construction phase: investigation

2.1 Chapter summary

This chapter explains how the design team can organise a comprehensive investigation concerning the building, its components, and its surroundings, to implement AIMES modules and highlight possible obstacles – somewhat a deepening or completion of the primary building inspection in relation to the chosen general strategy (see 1.3). It is estimated that the benefits of such investigation in terms of savings on the total project costs lie between 2% to 5% [1]. The output of the investigation phase is one or several survey documents/data files that address the following general topics:



What are the characteristics of the existing building and how do these impact the design of prefabricated façade modules?

- Suitability of the building and its surroundings to AIMES
- Hygrothermal and structural problems that need to be solved prior to the envelope upgrade or can be solved by the envelope upgrade
- Constraints in the design of AIMES façade modules and their related equipment

In particular, the following elements should be provided:

- A detailed evaluation of the performance and the condition of the existing building
 - o 'As built' description of the structure, envelope, and systems
 - o 'As maintained' condition of the structure, envelope, and systems with inventory of pathologies and thermal bridges
 - Hygrothermal behaviour assessment, energy performance assessment, users comfort and safety evaluation
- Load-bearing capacity of the walls, foundations, and other structural elements.
- Detailed geometry of the building (prefabricated façade modules often rely on CAD/CAM models during the production phase)
- Building surroundings parameters (factors that may have an impact on the construction site management, on the site accessibility, and on the choice of modules mounting devices)

To do so, different analysis methods can be applied:

- Visual inspection
- Imagery techniques
- Non-destructive measurements on site
- Destructive measurements on site
- Calculation
- Laboratory testing
- Simulations



The information stemming from this in-depth analysis will constitute a part of the framework conditions for the design of the prefabricated façade modules and their mounting. A comprehensive planning of data processing and data sharing steps is necessary and will help to elaborate the final design.

In practice, the project team will have to elaborate a detailed investigation plan with roles being properly addressed to the concerned actors and adequate communication paths. **Figure 16** shows the different constitutive step of an in-depth building investigation, with the different actors involved. The different investigation stages are not chronologically presented.

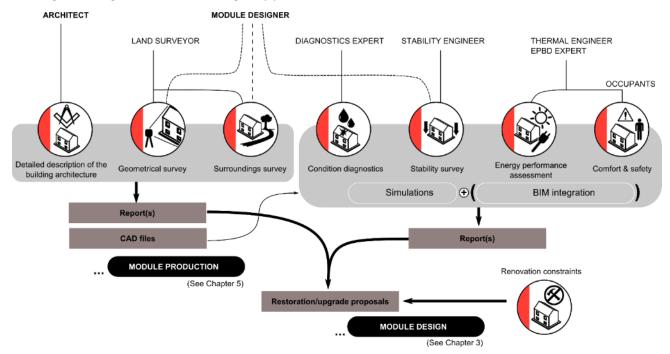


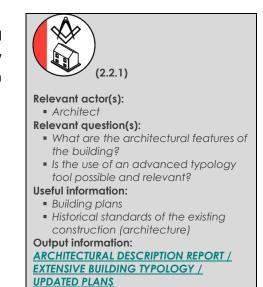
Figure 16. Action diagram for the investigation phase

2.2 Architectural analysis

2.2.1 In-depth description of the building architecture

In parallel with geometrical analyses, the in-depth architectural description of the building should be provided if it was not already done during the initiation phase. The relevant information includes:

- Features of the general construction of the building
 - Configuration of the load-bearing structure
 - Foundation type(s)
 - Roof type(s) and projections (roof overhang)
- Features of the individual housing units
 - Size/number/types of rooms
 - Features of sanitary rooms & technical spaces
- Floor plan
 - Heated and non-heated volumes on each storey
- Features of the envelope elements
 - Type/location/orientation





- Features of openings
 - Type/number/location/orientation
- Features of balconies
 - Type/number/location/orientation
- Features of main accesses
 - Number of main accesses
 - Features of stairways
 - o ..

More specifically, the project team should have the opportunity to rely on a precise 'as build' description of each individual building component, including structural elements (e.g. a load-bearing wall, a foundation slab), non-structural elements (e.g. a curtain wall, an internal partition) and HVAC systems. Such investigation looks at the type of component, its role, and its relevant sub-features (e.g. the material(s) from which the element is constructed with a possible multi-layered configuration). Existing documents, plans, and specific drawings should be collected with that aim, with a clear identification of the context in which they were produced (e.g. pre-project plans, permit plans, execution plans). The architectural analysis is of course intrinsically linked to the analysis of the resulting performance, which is described in section 2.3.

Various procedures can be found in the literature for supporting the identification and the classification of building elements. **Detailed typology tools for building components** were developed in some countries. For example, the Swiss typology [11] propose a very detailed systemisation of building components which are relevant to assess the added value of prefabricated refurbishment (**Figure 17**). We provide here some examples of systemisation tables (**Table 3** to **Table 6**) that illustrate how each building component can be characterised, a crucial step when planning the AIMES modules design. In complement, some illustrations from the 'TES Manual' are shown [1] (**Figure 18** to **Figure 20**).

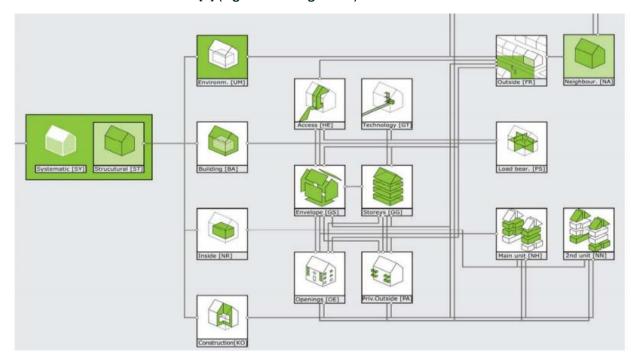
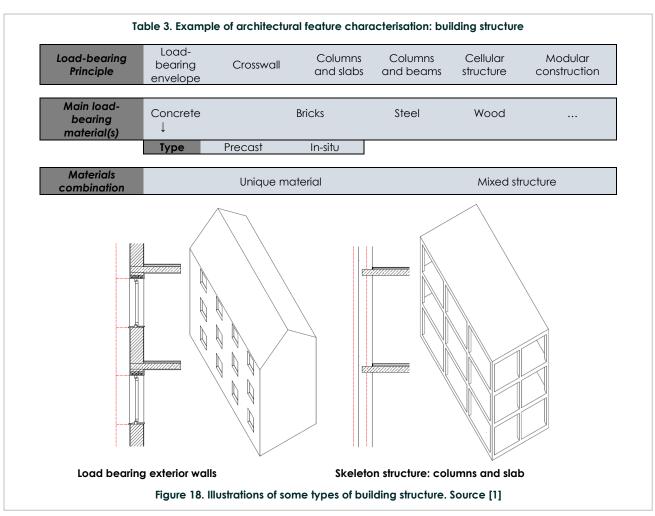
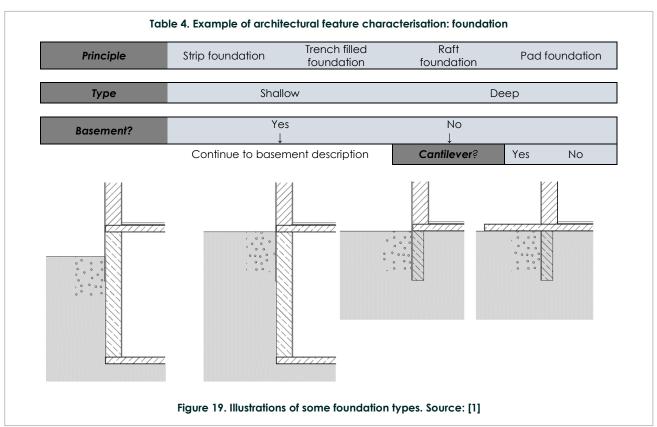


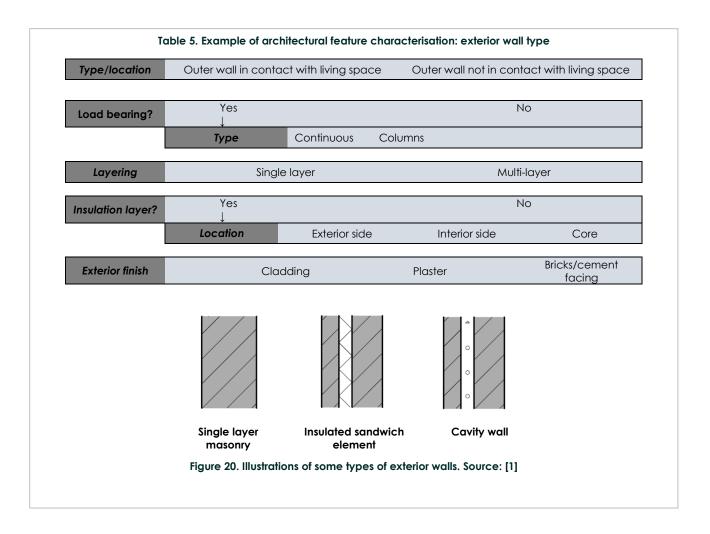
Figure 17. Broad view of the detailed characterization of building components developed in Switzerland. Source: [8]

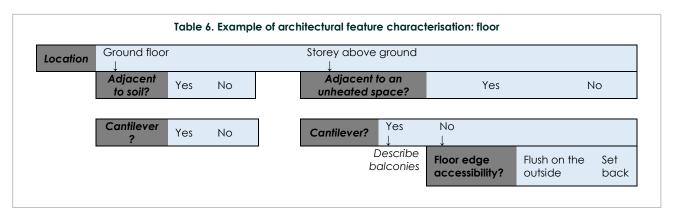














2.2.2 Geometrical survey

A retrofit project, especially when large-size prefabricated modules are involved, requires to gather precise information concerning the geometry of the building 'as it stands'. Large prefabricated AIMES elements are difficult to adjust on-site. In consequence, high accuracy geometrical data is crucial. In a first stage, this information will serve to assess the general feasibility of the retrofit technique as well as the best suited system. The analysis of the geometrical data can also provide background information for module design and, with additional post-processing of data, could directly serve the manufacturing process through CAD/CAM support (Figure 21, see 5.2.1). The main advantage of a well-thought geometrical survey is ultimately a significant reduction of on-site errors and subsequent costs.

A major concern with AIMES is the unevenness of the existing façade. In a majority of cases, the exposed surface will present irregularities that need to be evaluated and documented. Because the prefabricated façade modules will be rigid and can present large spans, the accommodation process can be particularly tricky. Approaching this problematic in a thoughtful way allows to limit on-site adjustments and to prevent potential future problems: the schedule, cost, and performance are guaranteed. Precisely, the 3D data stemming from the geometrical survey can be used to design the adaptation layer between the modules and the existing walls (see 3.4.2) and anticipate alignment efforts.

The goal of this section is to study the various techniques available to perform the geometrical survey, to compile an inventory of possible outputs files, and to analyse the parameters that intervene in the geometrical survey specifications. A Brussels case study is used to illustrate the statements (Figure 22).



Figure 22. Case study for geometrical survey in Brussels



Relevant actor(s):

- Architect
- AIMES designer
- AIMES producer
- Land surveyor
- (Occupants)

Relevant question(s):

- What is the exact geometry of the façade elements on which the modules will rely?
- What level of detail is required for its description?
- What is the maximum 'gap' to be recovered with the adjustment layer?
- What are the precise dimensions of the architectural features ('as maintained')?

Useful Information:



- Plans & drawings
- Photos

Output information:

GEOMETRICAL DATA / 3D & 2D MODELS



Figure 21. Final production plans for timber-based AIMES in <u>Augsburg (DE)</u>



(a) Available techniques

If hand measurements and simple apparatus like distance meters are excluded, **three categories of techniques** can be used to perform the geometrical survey. Often, a combination of techniques provides the best solution.

<u>Tacheometry (or Terrestrial Point Scanning-TPS)</u>

This first technique is the most traditional and is based on the assessment of the position of **discrete points** on the surface of the object by measuring distances together with vertical and horizontal angles. The devices evolved up to the modern and fully-automated 'total stations' (**Figure 23**), from which the coordinates of the scanned object can be uploaded on a computer for post-processing. The technique offers a **high fidelity but a large level of effort is required to increase the level of detail on the façade**, because of the time required to manually survey the points [12]. Moreover, whereas the technique is precise, there is a strong **user-dependent factor** in the compilation of results because the operator has to 'aim' chosen interest points on the façade. Therefore this method is often used to provide reference points for the two other techniques presented below.

Terrestrial Laser Scanning (TLS)

With the modern laser scanning methods, it is possible to obtain a detailed 3D representation of the building based on millions of points measured on the building surface. There exist various measurement principles for laser scanners but all based on the analysis of the reflected light from a laser beam over the surface of an object. These are so-called 'Light-Of-Sight' (LOS) instruments. Solid objects will thus cast 'shadows' and possibly create areas with missing data. That explains why the object needs to be captured from several positions to minimise such dark areas. A TLS can collect a great number of points per second and will generate what is called a 'point cloud' (Figure 24, Figure 25). The user has to define the field of view and the point density of the acquisition. The field of view represents the angular coverage of a scene whereas the point density lies in the definition of an angular increment or by a point spacing at a given distance. The resolution of the surveyed point cloud can reach values as low as 1mm. However, this 'grid' measurement principle requires geometrical extrapolations to represent the 'edges' of an architectural feature, which are not directly detectable (Figure 26, Figure 27). Some systems allow to perform average measurements, at the cost of a longer acquisition time.



Figure 23. Total station used in Augsburg (DE)

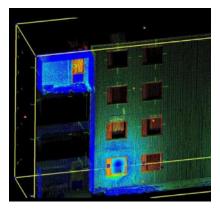


Figure 24. Raw 3D data from laser scanning with intensity values (Riihimäki, FIN)



Figure 25. Raw 3D data from laser scanning with RGB values (Brussels case study)



Depending of the device, each point is generally defined by at least:

- Its spatial coordinates (XYZ)
- An intensity value (the magnitude of the laser pulse back-scattered from the object surface)

There exist two types of laser scanners relevant for a building survey: the time-of-flight and phase-shift systems. The main differences in their properties are indicated in **Table 7**. Most of modern TLS devices are also equipped with a standard camera that allows to give colour information for each point (RGB values).

Table 7. Features of laser scanners. More features can be assessed from product databases³. Source: [13]

	Time-of-flight	Phase-shift
Acquisition frequency	10000 – 300000 points/s	~1 million points/s
Minimal distance	1 – 5 m	0.3 – 0.5 m
Maximal distance	300 – 6000 m	80 –180 m
Precision (length)	3 – 5 mm @50 m	2 – 3 mm @50 m
Precision (angle)	0.0002 - 0.01 °	0.001 - 0.007 °
Weight	10 – 20 kg	5 – 15 kg

Downstream of the capture phase, a labour-intensive task of data processing is necessary in order to generate useful information in the form of 2D drawings or 3D models. This phase includes: cleaning of models, merging the different point cloud, and possibly identifying and modelling architectural features. 'Orthophotos' can generally be created automatically from TLS data if the device provides RGB information. Such plane representation of façade can be very useful, for the drawing of elevations, AIMES design support, but also for the diagnosis of the building (Figure 28).

The relation between the actual scan time and the processing time can vary from 1:1 to 1:50, depending on the requirements of the survey [14]. One common problem is the manipulation of data, which can reach up to several dozens of gigabytes if a high resolution acquisition was performed or many point clouds are combined. Experience from the Swiss project *Nachhaltige Wohnbauerneureung* (CCEM) showed that a simplification of the raw point cloud by using horizontal sections through it, every 500mm, is then an interesting approach [14]. It drastically reduces the complexity of the raw data while still preserving useful information. The façade unevenness analysis, which requires a high density cloud, can be provided in the form of 2D images, with



Figure 26. Principle of TLS measurement. The edges of an object are not directly detectable (Brussels case study)



Figure 27. Raw data from TLS: The edges of an object are not directly detectable but the high resolution allows to find points really near to them (Brussels case study)

³ See www.geo-matching.com/category/id46-terrestrial-laser-scanners.html



a 'colour-map' that indicates the deviation from a reference vertical plan (Figure 29, Figure 30).



Figure 28. An 'Orthophoto', which is the equivalent of a textured elevation, can be created from TLS data (Brussels case study)

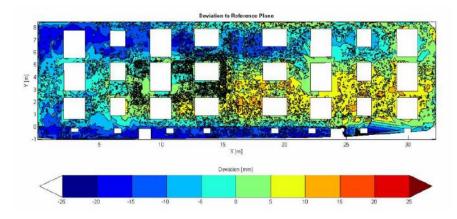


Figure 29. Possible 2D representation of façade unevenness with a colour map providing the deviation from a reference plane. Source: [1]

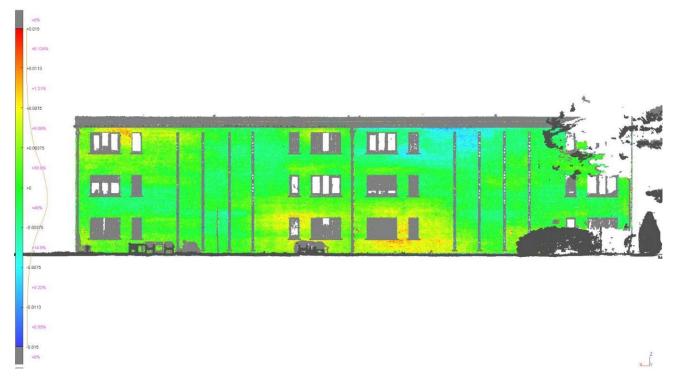


Figure 30. High resolution 2D representation of façade unevenness with irregularities distributions – here between +15 and - 15mm with respect to a vertical reference plane (Brussels case study)



Close Range Photogrammetry

Photogrammetry is a vast domain of techniques that can be defined as:

'The art, science and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring and interpreting photographic images and patterns of electromagnetic radiant imagery and other phenomena.'

(American Society for Photogrammetry and Remote Sensing)

The method appeared in the second half of the XIX century, just after the invention of photography. The advent of digital cameras, the evolution of their technical specifications, and the apparition of dedicated software for the computation and reconstruction process, have greatly enhanced its possibilities and enlarged its field of study. This document only refers to close-range photogrammetry, which refers itself to **the use of photographs with an object-to-camera distance of less than 300m**.

Method 1: Image rectification (Mono or multi-image)

For simple assessments, the rectification of images allows to get interesting results from single photo measurements, or multiple stitched photos. By **removing the distortion** caused by the camera lens, computation methods allow to recover dimensions of architectural features on a photograph by using the **main laws of perspective**. It requires that at least one dimension on the picture is known. For flat façades, some tools also allow to 'rectify' the perspective and create 'pseudo-orthophotos' (**Figure 31**). The technique does not require heavy computational processes but the results can present some artefacts if the façade features are located in several planes.



Figure 31. 'Pseudo-orthophoto' obtained from the lens distortion treatment and the perspective rectification (Brussels case study)

Method 2: Image-based modelling (Mono or multi-images)

The principle lies here in **recovering depth information on the basis of several pictures of a building or a building component.** A photo corresponds in fact to a particular **viewpoint on the studied object**. This method consists first in **manually selecting matching points** on several pictures (e.g. the corner of a specific window). Then, an algorithm spatially organise the pictures/viewpoints in the modelling environment. The object can then be drawn with 3D geometrical primitives from a chosen viewpoint using the associated picture as a guide. This method offers a solution for the **quick elaboration of volumetric models**, useful for energy models for example. However, obtaining detailed models requires many modelling efforts. Suchlike approach is not further detailed here because it does not 'produce' any geometrical information but rather offers a way to easily model the building.





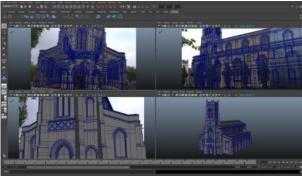


Figure 32. Image-based modelling. Source: [15]
(left) Pictures alignment by designating matching points from the different viewpoints (right) Modelling phase

Method 3: Multi-image orientation or 'Structure From Motion' (Multi-images)

This third technique is based on the **automatic exploitation of a great number of images**. The typical pipeline of a 'Structure From Motion' (SFM) software ultimately leads to the **3D reconstruction** of an object, which can be fairly similar to the output of a TLS equipped with a photographic sensor (x,y,z,R,G,B point cloud).

The process starts with the automatic determination of 'matching points' between the various projected views of the object. Then comes the computation of spatial transformations between those feature points and the estimation of camera poses for all images. A 'sparse cloud' of points on the building surface is obtained at that stage. Together with the development of computer vision, techniques for automatic detection of matching points ('Scale-invariant feature transform (SIFT) algorithm') have recently appeared and enriched classical photogrammetry approaches. Automatic matching detection allows to multiply the number of images analysed simultaneously, in contrast with the classical 'stereovision', which consists of using two views similarly to human vision, or image based modelling were the matching points have to be defined manually and the object has to be modelled from scratch.

Nowadays, modern software provides a high level of automation; accurate and high-density point clouds can be created from a series of photos (up to several hundred pictures processed). Moreover, the reconstruction of a 'dense point cloud' of the building is possible, using additional computation stages (see Figure 33). However, some factors can impinge upon the point cloud quality (Table 8). Another drawback of the method is the high computational power needed to compute a point cloud from a high number of photos.

Table 8. Factors that can impinge upon the point cloud accuracy with SFM method

Possible factors from studied object and the scene	Possible factors from camera and photographs
Reflective surfaces	 Low resolution
 Transparent surfaces 	 Artefacts: e.g. dust on lens
 Uniform textures 	 Noise: e.g. ISO too high, motion blur
 Moving light sources and shadows 	 Depth of field too low
 Direct sunshine 	 Insufficient 'Overlap' between photos
•	 Unsufficient number of viewpoints
	•



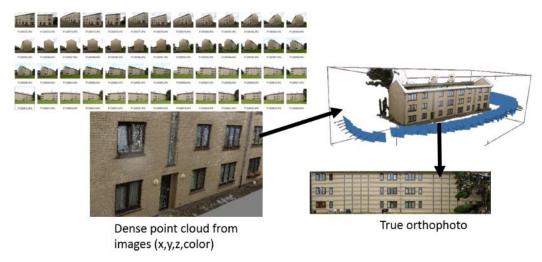


Figure 33. Use of SFM method to create a point cloud from simple photos (Brussels case study)

Even if a high level of detail can be obtained with a large number of photos, caution is required when using this method for the analysis of façade unevenness. For that matter, TLS provides more reliable results at the moment. SFM is still very useful to create orthophotos (similar to the ones created with TLS) or façade elevations. In addition, it is easily combined with aerial vehicles (see below). As a concluding remark, many tools exist in the domain of photogrammetry and there are many ongoing developments. Sometimes the boundaries are difficult to draw between the different techniques presented here. For example, some SFM software may offer possibilities for parametric modelling on the basis of the produced point cloud, which would be familiar to people accustomed to traditional image-based modelling.

(b) Remarks concerning the use of UAV for aerial surveying

Geometrical surveying with Unmanned Aerial Vehicles (UAVs) is gaining popularity (**Figure 34**). It should be referred rather to as a 'measurement vector' than a measurement technique. Indeed, these light flying vehicles can be equipped with geometrical surveying devices, opening access to some parts of the building that may be difficult to study otherwise (e.g. for high rise buildings, roofs). In its simplest form, an UAV can be equipped with a camera to gather a high number of pictures or videos around the building. These pictures can later be processed with SFM or image-rectification techniques.

In Belgium, the regulation concerning UAV usage has been issued in the form of a Royal Decree. Unfortunately, its contents impose many usage restrictions. More information can be found on a FAQ published on the Mobility section of the *Belgium.be* website⁴.



Figure 34. UAV used for photogrammetry measurements (Brussels case study)

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⁴ http://mobilit.belgium.be/fr/Resources/publications/luchtvaart/pub_luchthavens_faq_drones (FR) http://mobilit.belgium.be/nl/Resources/publicaties/luchtvaart/pub_luchthavens_faq_drones (NL)



(c) Survey objectives

The different actors should clearly state the objectives and deliverables of the geometrical survey such as:

- The architectural information to highlight
- The desired types of computer models (e.g point cloud, textured mesh, orthophotos) and their features given the intended final use (e.g. resolution of a point cloud)
- The potential evolvability of the models (i.e. would it be possible for someone to use the model as a basis for the development of a new one?). This matter is linked, amongst others, to:
 - the file format
 - the workflow used for the model development
 - o the libraries incorporated in the models
 - the modalities of georeferencing
- The acceptable measuring tolerance

The **objects**, **volumes** and **surfaces** of the **building** which need **surveying** should be mentioned clearly for the surveyor to elaborate a detailed scan plan, in order to maximise the adequacy of the resulting model with the AIMES designer's needs and to minimise the costs. The typical critical points that can be surveyed are shown in **Figure 35**:

- The exterior dimensions of each façade (outer edges and corners)
- The interior dimensions of rooms
- The level of structural elements to which the modules will be fixed
- The geometry of the eaves and roof overhangs
- The geometry of balconies and other out-of-plane elements
- The exact location and dimensions of existing openings, from inside and outside
- The unevenness of the façade surface, its curvature, and sloping walls
- Other structural pathologies (cracks, missing elements, ...)
- The height of the terrain
- Reference points

The survey objectives should also be translated into **common performance requirements**. The criteria mentioned in **Table 9** should be analysed when selecting a technique or a combination of techniques. **The tolerances of measurement, and the minimum artefact size** should also be controlled when inviting tenders for the geometrical survey. In the TES project, the distinction is made between:

- Acceptable tolerance when measuring discreet points (e.g. window edges or building corners): 7 10mm
- Acceptable tolerance when measuring the random points used to assess the façade unevenness:

Finally, it is important to specify the required precision for the absolute georeferencing of the model (if there were such requirement).



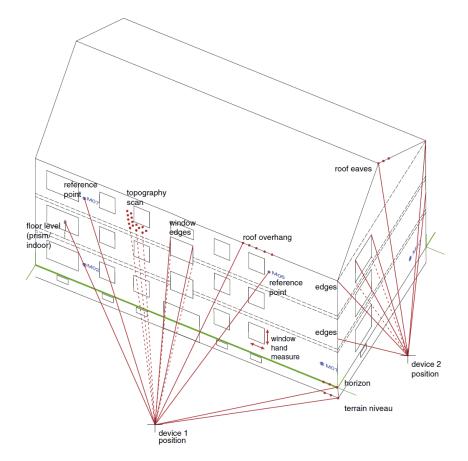


Table 9. Some performance criteria of surveying techniques

- Uncertainty/tolerance
- Level of detail
- Edge detection
- Model completeness
- Risks of interference
- Risks of poorly-defined zones
- Possible use in interior spaces
- ..

Figure 35. Measuring points and reference system for a geometrical model of the façade. Source: [1]

The **deliverables of the survey** are to be precisely defined by the design and production teams. The raw data stemming from surveying devices is generally not suited for design architects to work with and will require a processing phase to obtain usable 3D or 2D models.

Final 3D models may include:

- One or several cleaned high-density point clouds from scans (TLS) or reconstruction from multipleimage (SFM), which include the façade and possibly the interior spaces
- A combination of various cleaned point clouds in a single project file (very-high-density point cloud). This raw data can be so large that it would become difficult to exploit on standard computers.
- An **interpretation or simplification** of a point cloud. The openings and/or assemblies can be modelled by geometric or parametric representatives, which are adjusted to the measured points.
- A wireframe model of the façade derived from the raw point cloud or its interpretation
- A surface model, which is an enhanced version of the wireframe model with a triangulated façade surface
- A volumetric model of the exterior envelope (as image based modelling methods can produce)
- A full volumetric model, which includes the interior spaces
- A high resolution representation of the **surface topography** of one façade or façade element. It is extremely useful when assessing the adaptability of prefabricated façade modules on the existing walls. Knowing precisely the façade irregularities, the designer can choose an appropriate adaptation layer (see **3.4.2**), with a thickness that can be reduced to the minimum required to 'absorb' the shape of the existing walls.



As seen above, orthophotos are a first category of 2D output. More classically, 2D models can include plans, sections, elevations, or constructive details. These model are generally produced from the above-mentioned 3D models or from orthophotos.

Of course, many other important parameters intervene in the definition of the survey objectives. The project planning and the allowed budget for the geometrical survey are always decisive and can impose limitations on the possible studies.

(d) Potential challenges

The following potential challenges should be identified when redacting the geometrical survey solicitation (adapted from [16]):

- Technical issue that limits the use of one or several surveying techniques (e.g. a highly reflective building components will cause errors when using SFM, Figure 36)
- Required security clearance of the surveyor crew
- Obstructions caused by heavy vegetation or congested work spaces
- Access and time restrictions for the survey
- Security restrictions on the handling and storage of data
- Restrictions linked to the privacy of occupants

In some cases, it was proven that involving occupants by introducing and demonstrating the technology was useful to relieve apprehension and potential disruption of their work or living space [16].



Figure 36. Deformations on the cloud point produced by the SFM method, due to reflective materials (Brussels case study)

(e) Summary tables

Table 10. Summary table: TPS

Principe	 Discrete points assessed with the measurement of distances and angles (+ sometimes GPS information) Raw output = discrete points on the façade [xyz]
Precision / resolution	High intrinsic fidelity but the final precision is user-dependentLow resolution
Usage	 Very common technique Time for data acquisition: user-dependent ~10 points/min Time for data processing / final outputs creation = low
Material	Total stationSoftware
Remarks	 Used to provide geo-referenced points for all techniques Not adapted for façade unevenness assessment



Table 11. Summary table: TLS

Principe	 Detailed 3D representation from millions of points Raw output = point cloud of the building [xyz, intensity, reflectance, (colour)]
Precision / resolution	 High intrinsic fidelity and high resolution Edges cannot be detected
Usage	 Less common than TPS but gaining popularity Time for data acquisition with modern scanner: ~15min = 1 360° scan from 1 location (millions of points – capture all the complexity) Time for final point cloud creation = low (combination of sub-clouds) Time for data processing / final outputs creation = higher than TPS
Material	 Laser Scanner Target markers Software (generally provided by the scanner manufacturer)
Remarks	 True orthophotos can be created from the point cloud 'Big data' problem (enormous files, difficult to handle)

Table 12. Summary table: Photogrammetry - Image rectification

Principe	 Lens distortion and perspective rectification Based on 1 image Possibility of using stitched images Raw output = rectified pictures
Precision / resolution	 The precision depends on the software, the camera, and the presence of 'out-of-plan' architectural elements No info on surface unevenness
Usage	 Allows to get a rapid volumetric analysis of the building and pseudo-orthophotos (diagnostic, visualisation, elevations) Time for data acquisition: 3min = 30 photos Time for data processing / final outputs creation = low Possible with UAVs
Material	CameraSoftware (free solutions exist)

Table 13. Summary table: Photogrammetry - SFM

Principe	 Full 3D reconstruction from multiple images with automatic matching features detection, camera poses estimation and high- resolution pixel triangulation Raw output = point cloud or mesh of the building
Precision / resolution	 Potentially high fidelity and high resolution; depends on camera, software, image properties (e.g. pixel size) and capture scenario (e.g. overlapping factor of photos) Possible assessment of façade unevenness when many images are used
Usage	 Not common in the building sector Time for data acquisition: 10min = 100 photos taken manually Time for point cloud creation = high (increases exponentially with the number of photos to analyse) Time for data processing = Same as TLS Possible with UAV Require a high computational power (except for cloud-based solution) Some software are easy to use
Material	 Standard camera with at least 5MP (for good results) Software (free solutions exist)
Remarks	 Avoid: reflective surfaces / transparent surfaces / uniform textures / moving shadows (work best with diffuse light) True orthophotos can be created from the point cloud



Table 14. Comparison of methods for geometrical survey

	Point scanning	Laser scanning	Photogrammetry	
			Image rectification	Structure From Motion
Accuracy (XYZ dimensions of large architectural features / dimensional accuracy of orthophotos)	High to very high ¹	Very high	Low	Low to high ²
2d texture (RGB)	Not possible	Possible on some scanners (coloured cloud)	Possible (rectified image)	Possible (coloured cloud)
3d texture (small details in Z	Impossible in most	Possible with high	Impossible	Possible ³
dimension of the façade)	of the cases	accuracy		
Cost (material and software)	High	Very high	Very low	Low
Required skills (acquisition)	High	Low	Very low	Low
Required skills (data processing)	Low	High	Low	Very high
Acquisition time	High	Low	Very low	Low
Data processing time (to get usable data)	Low	High	Very low	Very high
Computer resources (producing files / manipulating files)	Very low	High	Low	Very high⁴

¹The accuracy depends on the operator for most of the systems

2.2.3 Building surroundings investigation

(a) Accessibility

Retrofitting from the outside with prefabricated modules requires some specific preconditions related to the site accessibility and the available ground space. On the building site, depending on the design and weight of the module, a more or less important space is required for temporary storage of these façade elements. A 'just-in-time' approach can possibly eliminate or at least limit this requirement. The equipment for lifting, possible tilting, and mounting the modules also requires adequate ground space (and a radius of action for manipulation of modules). Then, regarding the dimensions of modules and the type of truck required for their transportation from the factory to the site, accessibility (manoeuvre space) has to be granted along the delivery route, and on the site up to the storage location (see 5.2.8(a)). These are some crucial points related to the building surroundings to have in mind when choosing this particular retrofitting technique. Whereas composite exterior insulation system or small-size modules may only require a simple scaffolding, large dimensions modules rely on bigger auxiliaries⁵ (e.g. mobile cranes, trucks) to guarantee a quick and optimal mounting. In consequence, all possible obstacles in the surroundings environment have to be



(2.2.3)

Relevant actor(s):

- Architect
- AIMES designer
- Land surveyor
- (Experts: EPBD / transport & site loaistics)

Relevant question(s):

- Is the accessibility of the site guaranteed for the delivery of materials, equipment and modules?
- Is there space to store materials, equipment and modules?
- Which mounting/lifting systems are compatible with the site characteristics?
- Is the ground able to carry the load for delivery and mounting?
- What are the possibilities in terms of expansion of the building volume, given the properties of the site?
- How do the surroundings impact the daylighting conditions?

Useful information:



Output information:

SURROUNDINGS SURVEY REPORT / SURROUNDINGS 3D & 2D MODELS

²Able of 'very high' but the accuracy of SFM strongly depends on the quality of the photo set and the presence of problematic surfaces on the façade (e.g. reflective surfaces)

³SFM is still not the easiest way to assess the façade unevenness

⁴Cloud-based computing can reduce the required resource

⁵ Which doesn't mean larger cost due to the acceleration of on-site phase and the possible avoidance of scaffolding



documented. This task is often linked to the geometrical survey, because the laser-scanner and close-range photogrammetry techniques are adapted for the surroundings capture. More information for truck delivery is given in **5.2.8(a)**.

(b) Expansion of building dimensions

The prefabricated module retrofitting, like any other exterior insulation method, will cause an increase in the outer dimensions of the buildings. Another crucial consideration is the level of increase of the outer dimensions which is conceivable within urban code framework or considering any other legal restrictions.

(c) Other considerations

Many other aspects are linked to the direct environment of the building:

- Daylight: the local objects surrounding the building can impact its solar gain. In turn this has an impact on thermal balance and visual comfort.
- Integration of the building in a neighbourhood; the town-planning coherence.
- **...**

2.3 Evaluation of the building performance and condition

This step includes an in-depth description of the **building performance** as it was originally planned, as well as its current state (diagnosis) and the impact on the observed performance. It compiles the information needed to plan the interventions necessary to meet the new quality criteria fixed by the planning team. Moreover, some crucial data for the general design of the modules can be inferred (insulation thickness, protective layers, building services to be incorporated, potential anchorage points for façade modules, etc.). Weak points revealed during an advanced stage of planning, or worse during the construction phase, will cause higher cost and may hinder the planned schedule [14].

2.3.1 Condition diagnosis

Parallel to the detailed description of the building architecture, its condition has to be analysed precisely. Local problems that may require renovation interventions should be inventoried precisely. The design of the building also has to be analysed in the light of current standards.

(2.3)

Relevant actor(s):

See subtasks

Relevant question(s):

- What are the detailed features of the building and its components?
- How can its current condition be assessed comprehensively? (diagnosis and performance)
- How is it possible to remedy to the identified weak points/problems?

Output information:

See subtasks



(2.3.1)

Relevant actor(s):

- Architect
- Experts: Diagnostics
- (Experts: Building Physics / HVAC / Stability)

Relevant question(s):

- What is the condition of the various building components?
- Do some components show degradation that requires renovation intervention?
- What are the causes of the identified pathologies?
- How can the individual building components be characterised relatively to their hygrothermal performance?
- How could the condition of the building and its components impact the users' safety and comfort?

Useful information:



- (Inventory of building components, materials and assemblies)
- Database for hygrothermal properties of materials

Output information:

EXTENSIVE DIAGNOSIS REPORT / HAM MODELS FOR CONSTRUCTIVE NODES



(a) Damage diagnosis

This is the first part of the condition diagnosis, which focuses on the identification of existent pathologies, their sources, and the resulting damages. Depending on the considered building component, the types of damage can be variable: presence of cracks, excessive deformation, corrosion of metallic elements, biodegradation, mould growth (on wall surface, inside materials or in ventilation ducts), bad adhesion of the finishing layers, salt efflorescence... For each building element categorised during the in-depth architectural description, a diagnostic expert should identify existing problems, which should be remedied during the retrofit process. This remediation should always be combined with the identification of the causes of the problems, to avoid their resurgence. The possible root causes of degradation are multiple: water infiltration, unplanned loads, chemical alteration, or another pathology that causes a chain reaction with possible autoamplification effects (e.g. cracks in a render will cause water infiltration that in turn can give rise to further cracking due to freeze/thaw cycles). The core origin of pathologies is to be found in bad design, modification of the environmental conditions, or ageing of materials/assemblies. Regarding to AIMES, the integrity of floor slabs, foundations, and exterior walls is particularly important.

(b) Building physics diagnosis

The second stage on the condition analysis focuses on potential problems linked to the hygrothermal behaviour of individual materials or assemblies. For each material composing the envelope, **the hygrothermal properties should be accurately referenced** as well as its adequacy regarding modern standards and possible alterations that may impact the theoretical performance. The presence of any specific element that plays a role in heat propagation (by conduction, convection or radiation) should also be mentioned. The same goes for any elements that assure a role for airtightness, moisture regulation, sound transmission or fire safety. This information will be precious to identify which role the new AIMES modules have to fulfil, and the level of performance that should be aimed when designing the new envelope.

Geometry- or material-induced thermal bridges should be inventoried for remediation. Thermal imagery is very useful in this respect (**Figure 37**). In complement, some catalogue of thermal bridges exists and may help the Diagnostics expert to identify the typical heat losses coefficients. **The** *Kobra*⁶ **software** was developed at the BBRI for this purpose (**Figure 38**). If a more precise computation is needed, or the geometry departs from reference cases, 2D or 3D building element heat air and moisture models (BEHAM) can be used (e.g. *WUFI Pro, DELPHIN*). Existing balconies are one of the frequent locations of thermal bridges and the AIMES approach will allow to incorporate them in the heated volume. Alternatively, prefabricated balconies anchored to the new façade modules can replace the existing ones. **Any model elaborated during the investigation phase can also be used later to prospect the impact of the AIMES modules on the hygrothermal behaviour of the wall (design phase**).

⁶ http://www.cstc.be/homepage/index.cfm?cat=bbri&sub=rd&pag=projects&art=kobra_software



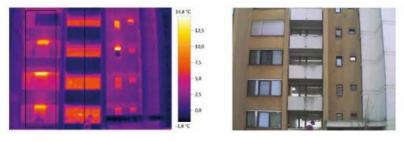


Figure 37. Thermal bridges highlighted by thermal imagery (Graz-2, AT)

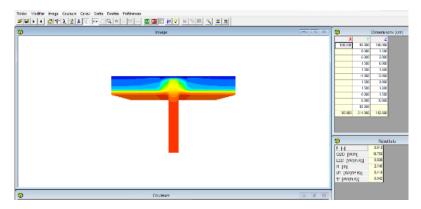


Figure 38. Kobra tool for thermal bridge identification in steady state conditions developed by the BBRI

2.3.2 Assessment of the overall energy performance

The Building Physics diagnosis addresses key issues related to the hygrothermal performance of building components and potential problems that could occur in the future. However, the hygrothermal behaviour of the existing building as a whole should be precisely characterised to implement a coherent and holistic retrofitting with improvement of energy efficiency and comfort for users through the use of prefabricated façade elements with integrated systems.

Generally, the overall energy use of the existing building should be evaluated early in the project. A method for measurement, validation by calculation, and results presentation is described in EN 15603 – Energy performance of buildings: Overall energy use and definition of energy ratings. Various monitoring campaigns can be considered in parallel, to identify strong and weak points in the behaviour of the building. The air tightness of the building plays a crucial role in its energy performance. The widespread 'blower-door' test allows to estimate energy leaks by air in-/exfiltration. (NBN EN 13829 – Thermal performance of buildings. Determination of air permeability of buildings. Fan pressurization method). The Technical Information Note (TIN) n°255 (BBRI) provides useful information related to air tightness design.

Additional energy efficiency analyses can be inferred from **whole-building numerical tools.** Such tools are based on thermal balance



(2.3.2)

Relevant actor(s):

- Architect
- Experts: EPBD / HVAC / Building Physics

Relevant question(s):

- How is the energy performance of the whole building evaluated with numerical and monitoring methods?
- How does the building energetically behave compared to similar buildings?
- How air tight is the building?
- What are the strong and weak points of the building with respect to its energy performance?
- What energetic measures offer the greatest score on a cost-benefit ratio?

Useful information:



- Inventory of building components, materials and assemblies
- 3d models
- Historical standards of the existing construction (energy design)

Output information:

ENERGY PERFORMANCE REPORT / ENERGY MODELS / HAM MODELS AT BUILDING SCALE



performed on each room, with loads from the exterior climate through ventilation and envelope transmission, and loads from interior sources, i.e. HVAC systems, lighting and occupancy. For each zone, the energy needs for heating and cooling can be assessed. The analysis of moisture transfers is generally limited to the modelling of indoor RH with sources from HVAC system and air infiltration. However, some complex models can include the coupled heat and moisture transfer inside the envelope. The Energy models created during the investigation phase can also be used to perform simulations in the design phase. The impact of several energy measures can be evaluated.

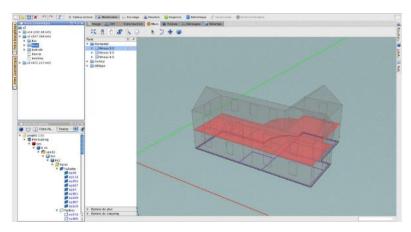
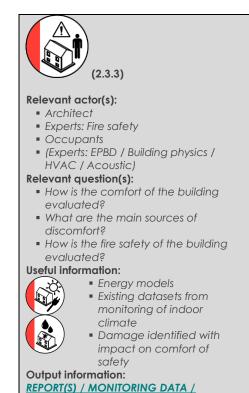


Figure 39. EPBD software for whole building energy performance assessment

2.3.3 Evaluation of users' safety and comfort

The occupants' comfort and satisfaction originate from the physical properties of the living spaces which translate into physiological reactions, but also from behavioural and psychological aspects. The hydrothermal, acoustical, visual, and respiratory comforts can be placed in the first category. The concerned physical parameters (e.g. temperature, light intensity, sound intensity) are well-known and limit values are defined in standards. The capacity for occupants to act on their environment is the behavioural part of comfort. Because indoor conditions and expectations vary in time, it is important that the tenant can intervene on the control devices of building systems (e.g. activate window blinds, reduce target temperature). The psychological part involves that the occupant is aware of how he can impact the indoor conditions. For example, a person with high environmental consciousness more easily accepts a relatively low temperature, if he knows that this contributes to fossil energy savings [17].

The various aspects of comfort should be studied in the existing building, in order to highlight how the new envelope can improve the users' satisfaction. Indeed, the integration of systems in AIMES modules can answer many problems linked to the existing building and associated discomfort causes. The choice of the materials composing the façade modules will also have a



OCCUPANT SURVEY(S)



strong impact. For this task of comfort assessment, monitoring and occupants surveying campaigns are very useful and will support the decision process.

As regards safety evaluation, fire (see **4.3**) and stability aspects (see **2.3.5**) are critical. Two aspects intervene: (1) how the building was conceived and on which standards was it based; (2) how the current condition of the envelope and the systems impact the original safety parameters. Hazardous materials present in the building should also be identified.

2.3.4 Definition of interventions constraints

These are **limits to the renovation for some specific building components** that can be either legal restrictions arising from the historical or architectural value of the element under a protection status, or any particular desire to preserve a part or the totality of its composition. Such constraints delimit the **'field of possibilities'** in the point of view of interventions (costs obviously present a second large type of limitation). The intervention constraints are not detailed in this document as they are very case-specific.

Once the diagnosis of the building has been established, with structural, hygrothermal or aesthetic issues associated to some specific building elements, the planner can propose a list of renovation interventions on the basis of experts' advises. These interventions can lie in the domain of classical renovations (e.g. injection against capillary water rise) or energy renovations (e.g. additional envelope insulation, windows replacement, HVAC upgrade). During the information processing phase, it will be determined which measures can be applied independently of the prefabricated modules retrofitting, and which ones can be solved by a proper design of the modules.



(2.3.4)

Relevant actor(s):

- Architect
- Experts: Diagnostics
- Owner

Relevant question(s):

- In addition to legal constraints, does the building operator have any requirements related to the preservation of specific building elements?
- What are the proposed renovation interventions validated by the concerned experts?
 - → 'Classical' interventions
 - Energy interventions

Useful information



 Problems identified during the diagnosis phase

Output information:

INVENTORY OF INTERVENTIONS
CONSTRAINTS / PROPOSALS FOR
RENOVATION INTERVENTIONS

2.3.5 Stability survey

(a) Basic concepts

In addition to the examination of the condition of the load-bearing structure during the diagnosis phase, a specific investigation phase should be carried out for assessing the **ability of the existing structure to support the new loads.** One must take into account that the accessibility to the supporting structure is not that easy, as some parts of the structure are hidden (by soil, surface finishing, etc.).

The inspection of the load-bearing capacity of a structure is defined mainly by **the weight of the AIMES module** and **the location of its anchorages**⁷ (see **3.6**). The stability investigation should thus be planned in close cooperation with the team in charge of module design. During and after the retrofitting of a building: safety

⁷ For a timber-based AIMES module with a U-value of 0.13 W/m²K, an additional weight of about 85 kg/m² of façade can be expected.



(Ultimate Limit State (ULS)), serviceability (Service Limit State (SLS)) and continued function (e.g. hospitals, offices) should be assured.

In the Eurocodes, the estimation of the design load-bearing capacity is ruled by a 'Probability of failure' factor, which can be determined on each building regarding the condition of its bearing components. This factor depends on risks and consequences of a collapse occurring. The 'Probability of failure' factor also varies with the estimation of the life expectancy of the building. It describes the security factor for building elements/materials and the amplification/reduction factor depending on the applied loads. Therefore, some investigations on the existing structure have to be conducted to allow the determination of these security factors. It includes: (1) visual analyses, (2) field investigations (possibly destructive), and (3) experimental evaluations if needed (tests in laboratory).

In addition to the architectural plans, the availability of the execution plans, former testing reports, or initial structural computations is important in such analysis as it may drastically reduce the investigation efforts. However, original documents are often lost, and thus, global and local surveys have to be realised to portray the load-bearing capacity.

Based on the preliminary inspections (visual inspections and field investigations), some feasibility questions will appear:

- Is it more interesting to repair or demolish the façade
- In case of doubt that could only be waived by expensive studies, is not it more practical to reinforce the structure (connections, foundations, etc.) even though it may not be necessary?
- Does the structure need some interventions as a safety measure (e.g. a new cover on exposed reinforcements - see Figure 40)?
- Is it interesting to test in laboratory elements that are possibly not safe?

The load reserve estimation can be crucial As an example, feedback from London (UK) project [18] showed that a failure in identifying the real shape of the building foundation and structural slabs can lead to unforeseen design and substantial execution delays.



Relevant actor(s):

- Architect
- Experts: Stability

Relevant question(s):

- What is the ability of the existing building to carry the additional load caused by the AIMES modules with possible volume extensions?
- What is the load reserve of foundations?
- What is the accessibility of structural elements?
- How can the stability of façade elements be characterised?
 - → Is a specific study for cavity walls necessary?

Useful information:



- Historical standards of the existing construction (stability design)
- Position, span and dimension of all load bearing parts
- Existing structural calculations
- Problems identified during the diagnosis phase with potential impact on the structural integrity of the building

Output information: STABILITY SURVEY / STRUCTURAL **COMPUTATIONS FILES**





(b) Soils and Foundations

Location, dimensions and geometry of the foundations

The actual dimensions and geometry of foundation slabs and footings are often different from those described in the original architectural drawings. Thereby, it is very important that the description of the foundation system also refers to execution reports if such are available. Geotechnical surveys can participate in expanding the available information (e.g. radar, sonar, ultrasonic methods) but only an excavation approach will bring a definitive answer (Figure 41). Once exposed, the concrete elements can be surveyed with a pachometer to characterise the locations of reinforcements (Figure 42).

Condition of the foundation

The main issue to estimate the condition of the foundations is its accessibility. In some buildings, there are cellars where the foundation walls are visible and their condition can be determined. However, the part of the foundation that is directly in contact with the ground is less obvious to perceive. Inspection throughout the soil can be conducted under certain stability conditions (e.g. see 'Infofiche 72.1 and 72.2 - BBRI') and then samples can be extracted to be tested in different ways if needed (evaluation of the compression resistance, level of oxidation, etc.).

(c) Anchorage of AIMES façade elements

AIMES modules shall be anchored in horizontal and/or vertical load-bearing elements of a building such as slabs and beams or walls and columns. Anchorage in existing concrete floor slabs (if such exists) is often chosen due to the high resistance of these structural elements. The study of the possible anchorage supports in the existing building and the analysis of their condition will allow to design an adequate configuration for the anchorage of AIMES (e.g. use of an attachment substructure, types of anchorage elements, and position of anchorage elements). Sometimes, obtaining information on the state and the nature of existing slabs is not that easy. Without execution plans of the building, field investigations have to be performed. These investigations can lead to the destruction of some parts of the ceiling, wall or floor finishing to access the desired information on load-bearing elements.

Non-destructive tools like endoscopes or pachometers can be used to fulfil the field investigations. An endoscope allows to obtain visual information in hard-to-reach spaces. Pachometers



Figure 40. Exposed concrete reinforcement. Source: [13]



Figure 41. Excavation to characterise the foundation system



Figure 42. Characterization of the foundation system with a pachometer



allow to survey the position of concrete reinforcements. If needed, **destructive devices** (e.g. jackhammer, drill) can give further information on the load-bearing layers.

2.4 Design parameters overview

The planning team has to process the information resulting from the investigation phase in order to fix realistic design objectives, which meet the owner's retrofit checklist (initial trigger for the retrofitting process) in the framework of the legal requirements (protected area in the buildings, energy efficiency policies, etc.), with a satisfactory response to the additional problems identified during the diagnosis, and within the allowed budget. These objectives will form the background of the module design and their mounting scheme. Table 15 provides a summary of the investigation stages. Their links with some relevant design parameters in the facade module conception phase are also highlighted. More detailed explanations are found in the next chapters.

Table 15. Overview of investigation steps with impact on the AIMES design

Investigatio	n stage	Output	Main parameters in façade module design
		ARCHITECTURAL DESCRIPTION REPORT / EXTENSIVE BUILDING TYPOLOGY / UPDATED PLANS	 Geometry and dimensions of modules Orientation of modules Choice of open or closed system Typical size of modules Fixation of modules Dispositions relative to fire safety and acoustic performance
Architectural analysis	N In the last of t	GEOMETRICAL DATA / 3D MODELS / 2D MODELS	 Geometry and dimension of modules (to cope with façade unevenness) "Levelling layer" properties (to cope with façade unevenness) Design of module openings
		REPORT / SURROUNDINGS 3D MODELS / SURROUNDINGS 2D MODELS	 Maximum weight of modules before transport Maximum dimensions of modules (given the manipulation space required) Preferential orientation of modules Windows blinds
Building condition and performance		EXTENSIVE DIAGNOSIS REPORT / MONITORING DATA / HAM MODELS FOR CONSTRUCTIVE NODES	 Assuring that no pathology is created or amplified by the chosen retrofitting process Choice of open/closed system Choices of integrated systems linked to ventilation
		REPORT / STRUCTURAL COMPUTATION FILES	 (From the type of the structure and the resulting load-bearing capacity) → Module anchorage configuration → Maximum weight of modules → Possibility of using the building foundation as support for the modules or need for a new foundation system (From the stability assessment of façade elements)
		ENERGY PERFORMANCE REPORT / ENERGY MODELS / HAM MODELS AT LARGE SCALE	 Module fixation systems Required insulation performance of modules Integrated technologies (windows, ventilation)
	REPORT / MONITORING DATA / OCCUPANT SURVEY(S)	 Choice of materials Integrated technologies (windows, ventilation or other services) 	
Intervention o	onstraints	INVENTORY OF INTERVENTIONS CONSTRAINTS / PROPOSALS FOR RENOVATION INTERVENTIONS	 External layer of the façade modules Maximum thickness of the retrofitted walls Possibility of implementing a centralised ventilation system (implementation of ducts in the indoor spaces)

3. Pre-construction phase: façade module design

3.1 Chapter summary

This chapter deals with the design of AIMES modules and their mounting system. We recall that the guidelines presented here are intended to provide recommendations for the AIMES solutions that present a sufficient feedback from Europe.

At present time, only few actors are familiar with the use of multifunctional prefabricated modules for retrofitting in Belgium, in comparison to other European countries (e.g. Germany, Austria or Switzerland). This results in an unavoidable familiarisation phase for companies willing to spread this innovative method. In



Which construction system for the prefabricated façade modules meet the building parameters that were compiled during the investigation phase?

this respect, timber-based structures are preferentially detailed in this document because the structural conception of such modules can rely on validated procedures and well-known materials assemblies. In literature, timber-based AIMES are generally referred to as 'TES' as it originated from *TES EnergyFacade* international project (see p.7). Only the implementation of façade modules on top of the existing walls (with the prospective removal of its external layer) is described in here, because of its somewhat more challenging aspect. Whereas major technical aspects are addressed in this chapter, additional information can be found in other reference documents continuously mentioned along the text. An example of a TES façade module applied on top of an existing façade is provided in Figure 43.

It should be recalled that the AIMES designation covers a wide range of design possibilities, in terms of module conception, module mounting configuration, and service systems integration. In the next sections, the following aspects of design are discussed in detail:

- Principle, form, and function: the 'type' of façade module, its general geometrical parameters and possibilities in terms of volume extension
- Layer composition: the possible choices of materials composing a façade module and the parameters that influence these choices
- Integrated systems: the design of integrated windows and technologies, e.g. decentralised ventilation systems
- Modules mounting layout: the detailing of the anchorage configuration, the fixation elements, and the chaining of modules

For each task and subtasks, the main design parameters are presented in summary tables which highlight specific attention points and provide elements for decision support. The contextual elements to have in mind are also mentioned. The current lack of diversity within executed AIMES solutions in Europe explains why the provided descriptions and illustrations are often related to the timber-based approach.



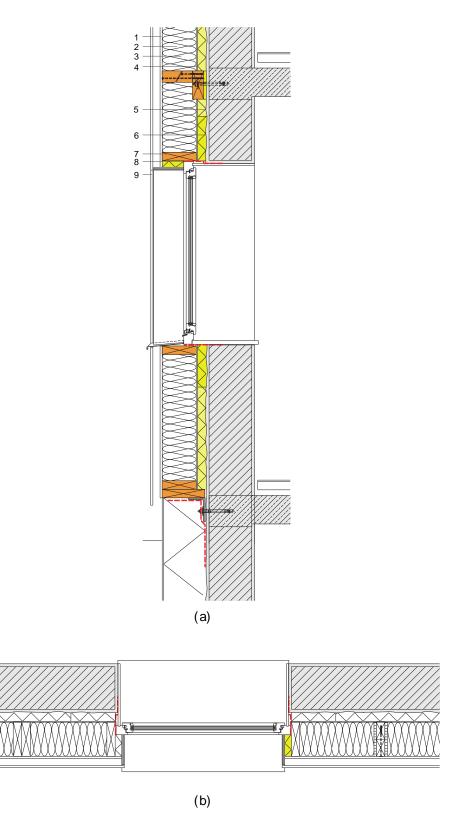


Figure 43. Example of a timber-based AIMES (TES). Source: [1]

- (a) Vertical cut section: 1. Gypsum board; 2. Cellulose insulation; 3. Stud; 4. OSB; 5. Adaptation layer; 6. Mineral wool; 7. Lintel; 8. Sealant; 9. Cladding
- (b) Horizontal cut section



3.2 Checklist for designing AIMES

When analysing tenders for any type of AIMES system, it should be primarily ensured that:

- The proposed system and his fixation elements complies with structural safety requirements
- The proposed system and his fixation elements complies with fire protection requirements
- The proposed system is suitable in terms of hygrothermal performance and moisture protection
- The proposed system does not cause degradation to the existing structure, or amplify any existing degradation phenomena, during its installation and for the design life-span of the new envelope
- No ventilated air space is created between the existing envelope and the new façade modules
- All connection and fixation details respect the above-mentioned points and are planned in such a way that clear specifications on execution are provided

More generally, **Figure 44** shows all the topics that should be kept in mind during the design phase. This includes the final objectives in terms of energy efficiency, occupants' comfort and safety, while taking building use parameters into account. Of course, the context parameters are also crucial and cover the characteristics of the existing building assessed during the investigation phase (see **Chapter 2**), but also the regulatory standards, the environmental exposure, and the project specifications. Finally, the impact of the design on the execution phase is considered.

MODULES DESIGN Layer Integrated Modules fixation Principe, form, CONTEXT **Existing building** (Investigation phase) and site management General constraints Legal context (standards, ...) **Project specifications** Retrofitted building Building use Energy efficiency Safety Comfort Stability Hygrotherma Moisture protection Visual

Figure 44. Overall diagram for the assessment of actions in design



3.3 Principle, form and function

3.3.1 Type of system

Two main 'types' of AIMES modules can be distinguished, namely the **closed and the open systems**.

The closed type is characterised by a flat back-face. It is either made of some structure closed off-site with boards or characterised by a sandwich panel configuration. An independent adaptation layer is necessary to fill the void space between the new envelope and the existing wall (see 3.4.2). A widely described example is the closed TES system (Figure 45): A wood structure is closed on both of its sides with sheathing boards and the main insulation layer of the module is almost always implemented off-site. Such closed TES modules often present a load-bearing capacity very similar to the ones used for new buildings construction.

The open type is necessarily made of a structure that is not closed on its back face when it is installed against the existing walls. The insulation layer is injected on-site and will absorb the irregularities of the walls. The adaptation layer is limited to some 'containment/sealing system' (e.g. compression tape) on the back edges of module frame and around window elements to avoid leakages when injecting the insulation material. The open TES modules provide a good example of such approach: there is no sheathing board on the rear side of the wood structure of the module. After the fixation of such 'empty' assembly on the existing walls, with adequate closure on the wooden frame on its back side, the insulation is injected via holes, which are pre-drilled off-site. The main resulting advantages of the open system are a simplified levelling process and a reduced weight of modules before mounting. This last characteristic allows to construct prefabricated elements with larger dimensions for an equivalent weight. However, the system is characterised by a greater segmentation of the assembly phase, which can lengthen the duration of on-site operations. A thermographic inspection might also be required to check the conformity of the insulation blowing. The main obstacle to a high prefabrication level with open systems is indeed bond to the accessibility of holes for blowing the insulation. From the inside, these can only be provided from around windows frames; from the outside, the cladding system needs to be partially completed or totally assembled on-site, with consequences on the scheduled works completion. Moreover, it



Relevant actor(s):

See subtasks

Relevant question(s):

• What are the general characteristics of the façade modules: their construction principle, their typical dimensions, their orientation, and the role they can play in assuring the enhancement of the building performance and users 'quality of life'?

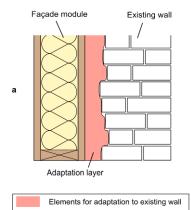
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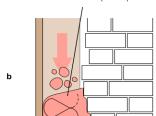
Relevant actor(s):

- Architect
- AIMES designer
- AIMES producer
- (Experts: EPBD / Building Physics / HVAC & building services / ...)

Relevant question(s):

- What type of system (Closed vs. Open) should be privileged?
- Is there an advantages of using a back panel?





Blown-in insulation (on-site)

Edge sealing

Figure 45. Timber-based modules types

(a) Closed TES with its adaptation layer; (b) open TES



can also affect the quality of the retrofit because wind and/or moisture protection elements will not benefit from the off-site control quality.

In <u>Kapfenberg</u> (AT) case study, **a hybrid system** is used, consisting in a timber-based structure closed with a vapour-tight membrane on is backside (**Figure 46**). The structure is filled off-site with loose-fill insulation and then the combination of insulation/membrane is pressed again the existing walls to absorb its irregularities.



Figure 46. 'Hybrid' system used in Kapfenberg

Table 16. Context parameters to study when choosing between the open or closed system

CONTEXT: PROJECT DEFINITION



- Legal: Fire safety requirements, requirements in terms of energy performance (U value),
 Building Physics requirements
- Goals: Planned environmental quality, planned extension of building volume, planned duration of on-site operations
- Linked design points: Layer composition of the modules, anchorage configuration and fixation elements, adaptation layer

CONTEXT: USEFUL INFORMATION FROM INVESTIGATION





- Type of structure of the existing building
- Large irregularities in the existing façade
- Load bearing capacity of the existing foundation and structure
- Condition of existing walls
- Hygrothermal behaviour of existing walls and existing moisture-related problems

Table 17. Remarks to support the decision-making between the open and the closed systems

REMARKS TO SUPPORT THE DECISION-MAKING: open or closed system?

- I. A closed system requires additional layers (e.g. back sheathing boards, adaptation layer)
- 1. More detailing is required
- 2. LCA and cost of the additional layers must be controlled
- 3. The additional weight of closed modules before transport can impact the delivering and manipulation...
- 4. ... However the open systems require a particular attention to the vapour tightness around openings (which can require the installation of a vapour membrane)
- II. An open system is often characterised by a lower prefabrication level
 - 1. Less quality control can be guaranteed
 - A higher segmentation of the on-site execution for the implementation of the external layer is likely...
 - 3. ... but closed systems require more complex operation for the implementation of the adaptation layer
 - There are less risks associated with moisture damage to the insulation during the transport and storage of modules
 - 5. Open systems are potentially more adapted for producers with low-tech assembly lines

III. An open system is associated to blown-in insulation

- 1. There is a need to plan and apply injection holes
- 2. There is a need to guarantee the accessibility to the injection holes (from the inside it will cause nuisance for occupants, or from the outside it will hinder the full prefabrication of the external layer of the module)
- 3. There is a need to ensure the adequate implementation of the insulation
- If cellulose is planned to be used, the fire safety requirements can be more complex to achieve



3.3.2 Geometrical parameters

In combination to the determination of the best-suited system type, an important step in the AIMES design process is to determine the general geometrical parameters of the façade modules: by playing on the orientation and dimensions of modules, much flexibility exists to adapt the prefabricated façade system to an existing building. In the respect of fire and stability safety requirements, and if several solutions are possible, the designer team should always choose a solution that limits the on- and off-site efforts. For example, it is always precious that windows elements are aligned within each module to limit the frame complexity and subsequent efforts for off-site production (Figure 49). To determine the optimal geometrical parameters, a particular attention should be given to the construction grids of the existing building [1] (axis, storey height, ring beams, etc.) and to the limits imposed by the site accessibility and the disposable machinery (for AIMES production, transport⁸, and installation). For example, the vertical orientation will require the tilting of modules after their delivery on-site; the weight of modules and handling possibilities will then play a critical role. If there are limitations in terms of space available for large lifting device, open modules should be considered because of their lower weight during installation.

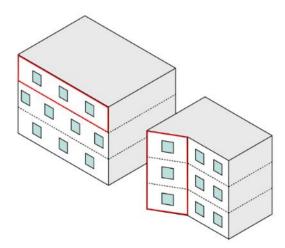


Figure 49. How the distribution of windows and the shape of the building can influence the choice of the module orientation

(3.3.2)

Relevant actor(s):

- Architect
- AIMES designer
- AIMES producer

Relevant question(s):

- How are the modules organised around the existing building?
- What are their typical dimensions (in the plan of the façade) and orientation?



Figure 47. Horizontal orientation in Augsburg (DE)



Figure 48. How the particular shape of the building (complex balconies) played a role in the choice of vertical modules orientation (Illustration: <u>Berlin</u>)

⁸ In most cases, the maximum size of a module is limited to 13x3.8m for transport restrictions



Table 18. Context parameters when choosing between the vertical or horizontal orientation

CONTEXT: PROJECT DEFINITION



- Legal: Fire safety requirements, requirements in terms of energy performance (Airtightness)
- Goals: Visual aspect sought for, planned duration of on-site operations, planned extension of the building volume
- Linked design points: Type of system, external layer, anchorage configuration and fixation elements

CONTEXT: USEFUL INFORMATION FROM INVESTIGATION





- Building shape
- Number of stories
- Functional distribution & construction grid (storey height, location of the ring beam, symmetry axis, alignment of openings, etc.)
- Façade unevenness
- Space available for the access of transport vehicles and for the manipulation of modules
- Load bearing-capacity of floor slabs

Table 19. Remarks to support the decision-making between vertical or horizontal orientation

REMARKS TO SUPPORT THE DECISION-MAKING: Vertical or horizontal orientation?

- For a wide building lower than 12m (4-storey) horizontal modules will produce a combination of horizontal and vertical joints between individual modules, whereas a vertical solution will create only vertical joints
- 1. More detailing is required
- 2. More aspects must be controlled on-site
- 3. More alignment efforts are required during the mounting of modules
- II. Vertical modules will span on several stories
 - 1. More complex approach for the control of vertical fire propagation is required
 - It is more difficult to distribute vertical loads at each storey → the load support is often located at base
- III. Vertical modules require tilting before mounting
 - 1. More manipulation space is required
 - 2. Adapted equipment is required

3.3.3 Building volume extension

European town planning measures have recently put much focus on increasing the density of the existing urban environment which can be achieved by extension of building spaces. The use of loadbearing prefabricated envelope elements opens great perspectives for space modification and/or extension (Figure 50, Figure 51). The topic is extensively studied in the second book of the *smartTES* project for timber-based AIMES [19]. Lightweight wood construction offers many ways to deeply transform the architectural appearance of buildings.

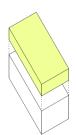
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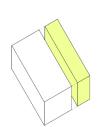
Relevant actor(s):

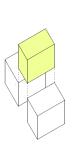
- Architect
- AIMES designer
- AIMES producer
- Owner
- (Experts: EPBD / Stability / ...)

Relevant question(s):

Is it possible to enlarge the volume of the building by using the loadbearing property of the façade modules?







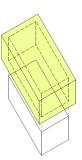


Figure 50. Different types of volume extension possible with AIMES. Source: [1]



The AIMES retrofits could be thought as only superimposing new façade elements in a somewhat 'flat' approach, but in reality a wide variety of possibilities exist for buildings owners and architects to **restructure façades and volumes composition (Figure 52)** with:

- Vertical extensions (storey addition, attic transformation, etc.)
- Horizontal extensions (integration of old balconies in the heated volume, new balconies, creating of new heated floor space, etc.)
- 'Fill-in' extensions

When studying the European cases, the integration of existing balconies in the heated volume constitutes the most frequent space conversion (Figure 53, Figure 54), followed by the addition of one storey. Various solutions exist to preserve the possibility for occupants to benefit from a living space with communication with the exterior. First, existing balconies can be transformed into winter gardens, like in <u>Augsburg</u>. The designer should keep in mind that innovative window elements exist for such a conversion, as the one shown in Figure 55. The AIMES modules that wrap the existing balconies should therefore be provided with large windows elements. New balconies can also be attached on AIMES elements, as designed in <u>Kapfenberg</u> project.





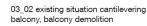
Figure 51. Use of AIMES modules for balcony incorporation in <u>Augsburg, DE</u> (left) or to create a new storey in <u>Pettenbach, AT</u> (right)



Figure 52. The example of Zürich (before/after) shows how the AIMES solution to create interesting architectural composition, far away from a classical 'flat' approach









balcony enclosure



balcony enclosure and new facade layer



new facade layer and addition of new balcony

Figure 53. Interventions on balconies with AIMES. Source: [1]





Figure 54. Balconies integration in Berlin (DE); illustration showing the different stages of the process

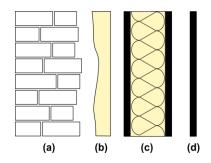


Figure 55. Innovative window solutions to create winter gardens from former balconies



3.4 Layer composition

An AIMES façade module consists of a series of layers, each of which plays one or several roles: structural, thermal insulation, fire safety, air tightness, aesthetical, etc. For closed systems, the layers are typically assembled as indicated on **Figure 56**.



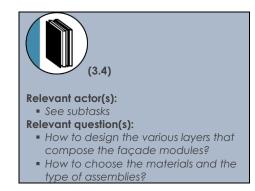


Figure 56. Typical layer composition of a closed system. Source: [1]
(a) Existing wall; (b) adaptation layer; (c) 'core' of the module with insulation layer(s); (d) external layer/cladding system

With open systems, the design of an adaptation layer is limited to specific zones because the absorption of the façade irregularities is primarily undertaken by the blown-in insulation layer.

The following subsections describe the tasks linked to the conception of the different layers, which covers choices in terms of materials and assembly modalities. The selected composition may require some specific modifications according to the final location of modules in the building. All the design tasks should be considered in an integrated approach with regards to the module behaviour as a whole, and with an analysis of structural, hygrothermal, fire, and sound reactions.

3.4.1 Core layer

The 'core layer' (see **Figure 56-c**) is defined as the layer that contains the structural elements as well as the main insulation layer(s). It possibly integrates some building technologies and technical layers (e.g. vapour retarder). His location is between the adaptation layer and the finishing layer.

There are many available products for wall insulation ranging from high-performance and highly-processed products to low-grey-energy bio-based products. The aspects to have in mind when designing the main insulation layer are:

- The reaction to fire of the material (according to NBN EN 13501)
- The lambda-value of the material (NBN EN 12667)

(3.4.1)

Relevant actor(s):

- Architect
- AIMES designer
- AIMES producer
- (Experts: EPBD / Building Physics / HVAC & building services / ...)

Relevant question(s):

- What are the relevant parameters for choosing the type of structural timber, the insulation characteristics, and the type of sheathing boards?
- Which features of the existing buildings or other framework conditions influence these choices?
- What materials offer a good compromise between cost/performance?
- How are the materials assembled?



- The thickness required to comply with the aimed U-value, taking into account the properties and spatial configuration of the other structural elements (NBN B 62-002)
- The material density and the resulting weight of the largest façade module given the required thickness
- For loose-fill materials: risks of compaction (NBN EN 14064)
- The reaction to water (vapour permeability, adsorption isotherm, water suction) and potential impact of water on its physical characteristics
- Environmental indicators based on LCA

These parameters have to be considered in the light of the context parameters as for example the limitations in terms of wall thickness expansion or the fire class of the building. Some precisions concerning Building Physics design are compiled in Chapter 4. When retrofitting with AIMES on top of cavity walls, the possibility of post-insulating the cavity⁹ should be studied. It allows to reduce the AIMES insulation thickness. However, this solution is deeply intertwined with stability issues and saving the existing brick face is not always economically/technically viable.

Examples of insulation materials

- Solid products (boards or mats)
- Mineral wool (MW) NBN EN 13162
- Expanded Polystyrene (EPS) NBN EN 13163
- Extruded polystyrene (XPS) NBN EN 13164
- Rigid polyurethane or polyisocyanurate foam (PUR/PIR) – NBN EN 13165
- Phenolic foam (PF) NBN EN
 13166
- Cellular glass (CG) NBN EN 13167
- Wood wool (WW) NBN EN 13168
- Expanded perlite (EPB) NBNEN 13169
- Wood fibre (WF) NBN EN 13171
- o Aerogels & VIP's
- Loose-fill products
 - o Mineral wool NBN EN 14064
 - o Cellulose
 - Aerogels

Also, the choice of the insulation material is intrinsically linked to the structural elements which are planned to be used within the AIMES modules. In timber-based design, the main insulation layer is located between structural timber studs that can be of several types (Figure 57). The primary structure is sometimes supplemented by a secondary perpendicular structure (Figure 58) which allows a larger thickness of insulation without adding too much to the weight of the structural skeleton or risking thermal bridge effects. An alternative to the cross-layered solid wood structure for high thickness modules is the use of wooden I-beams or other composite systems (Figure 57). The horizontal inter-spacing between the studs depends on the expected load-bearing capacity as well as the standard size of sheathing boards, similarly to timber construction methods for new buildings. Open TES requires loose-fill materials whereas closed modules can accommodate for either board or loose-fill insulation. A loose-fill material will require additional precaution as compaction or differential settlement can occur. Cellulose is a popular loose-fill material but its sensitivity to fire and moisture should always be kept in mind. When the insulation material is applied off-site, a possible alteration of the material during transport and mounting phase should be anticipated.

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⁹ See the TIN 246 (BBRI)



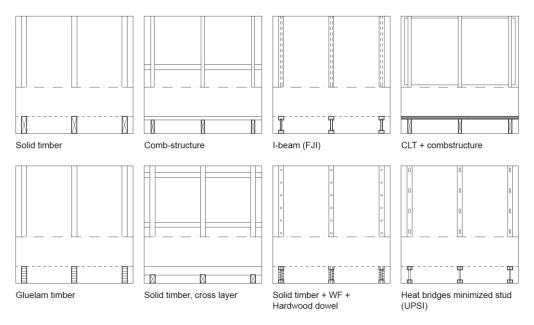


Figure 57. Choices for structure design for TES. Source: [1]

A particular class of insulation materials with extremely high insulation capacities appeared recently. **Aerogels** are characterised by a total porosity of about 97-99% resulting in the lowest known density of a solid material. The typical pore size (about 20nm) is smaller than the mean free path of air molecules, which explains the particularly low thermal conductivity. These materials, sometimes referred to as 'frozen smoke', can be produced from a variety of substances, although silica and water glass aerogels remain the most studied ones. Today, blanket or particles aerogel products are available for building applications, e.g. loose-fill insulation in the air gap of a cavity wall. **For AIMES,**



Figure 58. Cross-layered TES structure (Riihimäki)

such high performance products could be considered for the main insulation layer in the future with innovative forms of façade modules (e.g. composite panels). For TES-like design and in the current context, they can be used sparsely in the detailed design plans to accommodate for local weakness of the thermal insulation layer, for example in front of roller blinds, or where building technologies are incorporated.

For the core layers that are based on a structure, several requirements are to be met when designing the front and back sealing (usually with sheathing boards). The first important question to be asked concerns the relevance of the inner panelling (facing the existing structure) and refers to the choice of open or closed configuration. It should be recalled that if the modules are planned to be pre-filled in the factory, a containment layer is to be planned on the back side of the module. In addition to its structural and containment role, a panel intervenes in the physical behaviour of the timber-based AIMES module and thus on its final performance. A well thought layer of the modules guarantees the safety and comfort of occupants.



Table 22 summarises important attention points to have in mind when choosing the panels and any additional technical screen.

Table 20. Context parameters to analyse when designing the core layer

CONTEXT: PROJECT DEFINITION



- Legal: Fire safety requirements, requirements in terms of energy performance, Building Physics requirements
- Goals: planned environmental quality, new U-value aimed for the envelope
- Linked design points: Type of system, orientation of modules

CONTEXT: USEFUL INFORMATION FROM INVESTIGATION





- U-value of the existing walls
- Hygrothermal behaviour of existing walls
- Moisture content of existing walls
- Roof overhang
- Number of stories / fire class
- Acceptable thickness of the new wall (e.g. city code)
- Load bearing capacity of existing foundation and structure

Table 21. Design parameters and attention points for designing the core layer

DESIGN PARAMETERS AND ATTENTION POINTS

- I. Concerning the properties and performance of materials
 - LCA and cost*
- 2. Density
- 3. Lambda-Value*
- 4. Reaction to water and mould growth risk
- 5. Fire reaction (EN 12501)

II. Concerning the assembly details

- 1. Fastener systems
- 2. Technical layers (sheets, bands, joints)
- 3. Local adjustments
- 4. Impact of above-mentioned points on the performance of the final assembly
 - a. Weight of façade modules before transport
 - b. Final weight of façade modules and resulting loads on the existing structure
 - c. Self-standing and load-bearing capacity of façade modules
 - d. Fire resistance
 - e. U-Value
 - f. Acoustic performance
 - g. Hygrothermal behaviour and expected level of relative humidity in materials**
 - h. Risks of thermal bridges**

III. Concerning exexution

- 1. Off-site phase
 - a. Modalities of assembly in factory and required equipment
 - b. Weight of modules before transport/mounting
- 2. On-site phase
 - a. Planning of the external/cladding layer implementation & weather protection***

^{*}Insulation materials with the lower thermal conductivity are not necessarily the ones with the lowest impact in a LCA. However, at equal performance, they will result in a thinner wall.

^{**} If the new façade modules are applied on the existing walls, Building Element, Heat, Air and Moisture (BEHAM) simulations with specialised tools should be considered [1]

^{***} During on-site operations, adequate protection measures should be taken for material that show a high sensibility to moisture. This is especially true when the weather-protective layer of the module is implemented after the module fixation.



Table 22. Specific attention points when designing the panelling of a TES façade module

	Outer panel (+ screen)	Insulation/structure	Inner panel
Closed TES (on existing wall)			
Fire resistance	X	(x)*	(x)*
Vapour retarder	-	-	(x)
Wind protection	X**	-	-
Rain protection	(x)***	-	-
Sound protection	X	(x)	(x)
Open TES (on existing wall)			
Fire resistance	×	(x)*	
Vapour retarder***	-	-	
Wind protection	X**	-	
Rain protection	(x)***	-	
Sound protection	×	(x)	

x = mandatory, (x) = to be checked, - = not relevant

3.4.2 Adaptation layer

The surface of the existing walls will always presents some irregularities, which can be more or less pronounced and were supposedly evaluated during the geometrical survey. The back face of a closed module or the structure of an open module are in turn perfectly straight. **Ultimately, after mounting operations, the contact between the existing façade and the new envelope elements needs to be perfect. The use of a 'filling' approach is necessary:** a material will thus fill the gap that exists between the irregular existing walls and the planar surfaces that composes the new façade modules – an adaptation layer.

The adaptation layer needs to be thoughtfully conceived as any residual space might result in potential damage or decreased performance. This interface also play a major role in the levelling operations of new façade modules. The use of a substructure, attached to the structure of the existing building in a first phase, will allow to simplify the levelling process during the mounting of modules and offer clear attachment points. Several variations in the conception of the adaptation layer can be inventoried and are detailed hereafter.

(3.4.2) Relevant actor(s):

- Architect
- AIMES designer
- AIMES producer
- (Experts: Stability / Building Physics / HVAC and building services / ...)

Relevant question(s):

How to fill the cavity between the existing wall and the new modules?



Figure 59. Example of a full-span compression layer for closed TES installed on-site in Oulu (FIN)

(a) For closed AIMES systems

The first option for designing an adaptation layer consists in placing an additional **compressive insulation layer on the back of the AIMES module** that will be used to level the façade modules. The required thickness of this mat will depend on the façade unevenness and the constitutive material. Here, 3D datasets gathered during the investigation phase are particularly precious (see **2.2.2**). This method is referred to as a 'full-span' layer

^{*}All elements that compose the modules play a role in its final fire resistance. The insulation layer and the inner panel should not necessary be incombustible but their fire behaviour should be well understood to guarantee fire safety ** Wind protection is crucial, to avoid that cold exterior air penetrates towards the adaptation layer. Besides from infiltration through the exterior board, a typical location for the wind protection is at the location of joints between modules

^{***} The outer panel system should be rain-proof (rain screen) depending on the cladding system (see 3.4.3)



because the compression mat covers the entire surface of the back panels. This technique is not frequent but was used in Oulu (FIN) with horizontal TES modules (Figure 59).

Alternatively, a levelling substructure can be fixed on the existing walls and will serve as an attachment lath for modules. Two possibilities exist for the purpose of filling the void laterally between the levelling laths. Either a compression layer, generally mineral wool, either a loose-fill insulation blown after the mounting of façade modules. For the second option, the 'TES manual' recommends a cavity with a width of at least 30mm. Another design parameter is the orientation of the levelling laths (Figure 60). Globally, many solutions exists for designing the adaptation/levelling layer of a closed TES module. Figure 61 provides an overview of some of solutions for timber-based AIMES with chronological mounting operations.



Figure 60. Use of a substructure
(left) Horizontal levelling substructure for vertical modules in <u>Riihimäki</u> (FIN)
(right) Vertical levelling substructure for horizontal modules in <u>Graz</u> (AT)

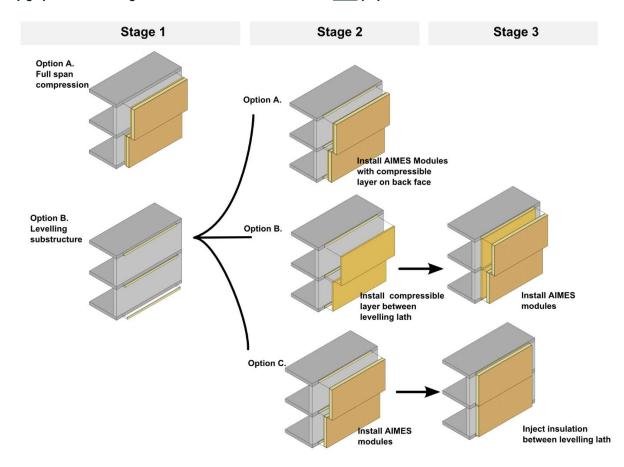


Figure 61. Various systems for the adaptation layer of closed structure systems with horizontal orientation. Only the horizontal layout for the substructure is illustrated here in detail



Table 23. Context parameters to analyse when designing the adaptation layer for a closed system

CONTEXT: PROJECT DEFINITION



- Legal: Fire safety requirements
- Goals: Planned environmental quality, planned duration of on-site operations
- Climate: Wind loads
- Linked design points: load-bearing configuration and fixation system

CONTEXT: USEFUL INFORMATION FROM





- Level of irregularities on existing façade
- Number of stories / fire class
- Condition and load-bearing capacity of floor slabs
- Accessibility to floor slabs from exterior

Table 24. Design parameters and attention points when designing the adaptation layer for a closed system

DESIGN PARAMETERS AND ATTENTION POINTS

OPTION 1: Full-span compression layer

I. Concerning the properties and performance of materials

- 1. LCA and cost of materials
- 2. Lambda-value of materials and impact of compression on the lambda value
- 3. Fire reaction (EN 12501)

II. Concerning the assembly details

- 1. Fastener systems and construction details
- 2. Impact of the above-mentioned points on the performance of the final assembly:
 - a. Fire resistance
- b. Air tightness

III. Concerning execution

- 1. Off-site phase
 - a. Modalities of the assembly and equipment required in factory (if the compression layer is fixed to modules off-site)
 - b. Weight of modules before transport/mounting (if the compression layer is fixed to modules off-site)
- 2. On-site phase
 - a. Risks of damage during transport
- Required equipment for the fixation of the compression layer (if it is fixed to the existing walls or to modules on-site)

OPTION 2: Substructure + in-between insulation

I. Concerning the properties and performance of materials

- 1. LCA and cost of materials
- 2. Lambda-value of the in-between material
 - a. Impact of compression on the lambda value (if the in-between insulation is a compressive layer)
 - b. Impact of a possible compaction on the lambda value (if the in-between insulation is blown)
- 3. Fire reaction of the in-between insulation (EN 12501)
- 4. Resistance to structural efforts of the components of the substructure assembly

II. Concerning the assembly details

- 1. Fastener systems and construction details (e.g. anchorage points of the substructure)
- 2. Required technical layers (sheets, bands, joints)
- 3. Impact of above-mentioned points on the performance of the final assembly:
 - a. Fire resistance
 - b. Structural safety
 - c. Acoustic performance
 - d. Risks of thermal bridges

III. Concerning execution

- 1. On-site phase
 - a. Required equipment for the mounting
 - b. Phasing of mounting



Table 25. Remarks to support the decision-making when choosing the adaptation layer for a closed system

REMARKS TO SUPPORT THE DECISION-MAKING: need of a levelling substructure?

- I. A substructure creates a flat and aligned support for the modules fixation
 - 1. An accelerated module mounting phase is guaranteed but...
- 2. ...More operations are required before the mounting of the modules
- A substructure lowers the risks of facing an alignement/anchorage problem when mounting the modules
- II. The substructure and the in-between insulation require weather protection whereas the full-span compression layer can be assembled off-site
- III. The substructure system can be combined with blown-in insulation materials
 - 1. Requires the design of an adequate lateral sealing and...
 - 2. ...Requires to provide holes for injection with easy access (can be difficult!)
 - 3. Moreover, some loose-fill insulation materials are particularly sensitive to moisture and once injected, the possibilty of drying is low

(b) For open AIMES systems

For open systems, the main insulation material, which is injected between the structural studs after mounting the modules, guarantees the absence of air between the existing wall and the AIMES element (Figure 62). However, this requires an adequate sealing on the edges of the AIMES modules in order to ensure the containment of the blown-in insulation as well as proper air tightness (Figure 63). This can be done by an airtight compression band placed on the back face of timber elements of the module (method used in Berlin project) or foam combined with tape (Pettenbach, AT). One advantage of the open system compared to a compressed adaptation layer (current solution for closed



Figure 62. Prototype illustrating the blown adaptation layer (<u>Pettenbach</u>, AT)

systems) is that the thickness provided to accommodate for the façade unevenness will actually participate in the wall insulation.

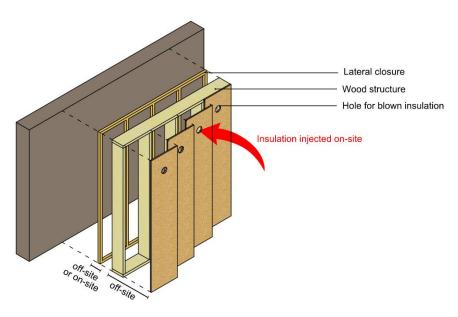


Figure 63. Flakes/particles layer injected after assembly





Figure 64. Mineral wool flakes blown into the timber elements after assembly in Berlin (DE) (left) Installation of 'compriband' on the back of the open TES (middle) Lifting of a module before installation (right) Injection of the insulation material from the inside

Table 26. Design parameters and attention points when designing the adaptation layer for an open system

SOME DESIGN PARAMETERS AND ATTENTION POINTS

- Concerning the properties and performance of materials
- LCA and cost of materials
- Lambda-value of blown-in materials and impact of a possible compaction on the lambda value
- Fire reaction (EN 12501)

Concerning the assembly details

- 1. Fastener systems et construction details
- Design of the lateral sealing
 - a. Maximum compression of the sealing material (to be compared to the critical points observed during the façade unevenness survey)
 - b. Risks of fire propagation through the lateral sealing
- c. Risks of air convection throughd. Lifetime of the sealing system Risks of air convection through the lateral sealing
- e. Modalities of sealing implementation
- 3. Design of injection holes
 - a. Impact on the prefabrication level
 - b. Accessibility for the injection... (\rightarrow provide another method locally if necessary)
- Impact of the above-mentioned points on the performance of the final assembly:
- a. Thermal performance
- Fire resistance

III. Concerning execution

- On-site phase
 - a. Modalities of injection
- Modalities for the protection of modules before injection and before the implementation of the external layer (e.g. the external cladding)

3.4.3 External layer of the façade module

The materials composing the external layer of the AIMES façade modules need to be chosen in the light of architectural, aesthetical and performance criteria. In particular, specific requirements in terms of weather and vandalism protection should be defined. There is large flexibility in the choice of cladding materials that cover the entire area of façade modules (or a part of it if solar technologies are used): massive wood cladding, wood particle boards, natural stone, brick strips, copper sheets, zinc, steel, etc. (Figure 65)

Table 27, adapted from the 'TES Manual' [1] for the Belgian situation, provides an insight on the many available choices.



To achieve the highest energy performance standards, high thickness thermal insulation is generally required. However, the very high thickness walls pose problems of space, lighting, etc. This is particularly the case in renovation. Innovative passive solar panels could replace a part of the required thermal insulation. These panels are made of glazing, behind which are a ventilated air gap and a specific structure of cellulose or wood. This structure, respectively alveolar (Figure 67) or lamellar (Figure 68), captures sunlight to create a buffer zone whose temperature is higher than the outside air. The temperature gradient across the wall being substantially reduced, the heat losses by transmission through the wall are diminished. It can also be referred to as a 'solar responsive façade' [20].

The system operates on a day-night cycle, the energy of sunlight is captured and stored in the form of heat during the day, the heat reserve then flowing overnight. The operation of the system also depends on the season. In summer, the very oblique rays of the sun hardly penetrate the alveolar or lamellar structure. The system therefore absorbs little energy and the ventilated cavity helps to prevent overheating. In winter, the almost horizontal sunlight penetrates the alveolar or lamellar structure, thereby heating the air in the hollow zones and the mass of the underlying material. Fresh air in the air gap causes less convection than in summer, creating an additional insulating layer.

In achieved European projects, passive solar panels are typically used on top of a closed timber-based system to reach a high level of performance. Much information concerning these solar systems can be found in the 'Retrofit module design guide' from IEA Annex 50 [21]. Such systems require additional validation in Belgium as they do not fall under any current standard. Moreover, assessing their performance in the EPB Software is not possible.

(3.4.3)

Relevant actor(s):

- Architect
- AIMES designerAIMES producer
- Owner
- (Experts: EPBD / Building Physics / HVAC & building services / ...)
- (Subcontractor for the external layer)

Relevant questions/themes:

- Which role is the external layer expected to play?
- Is the moisture-safety ensured for all life stages of the building?
- Are solar panels planned to be integrated on the new facade?
- Which implementation mode is more relevant regarding other aspects of design and organisation: off-site or on-site?



Figure 65. Various solutions for the external layer (top-left) Natural slates in Roosendaal, NL; (top-right) plaster in Riihimäki; (bottom-left) HPL panels in Berlin; (bottom-right) 'Solar façade'





in Graz (AT)

Figure 66. Cladding installation
(left) Wood board cladding incorporated off-site (<u>London, UK</u>); (right) wood battens incorporated off-site and cladding onsite (<u>Oulu, FIN</u>)



Table 27. Solutions for the external layer of AIMES modules (adapted from [1])

External layer system	Layers	Standards or reference
Brick or stone strips	Adhesive layer, mineral strips	NBN EN 771-1, NBN EN 10545-12, ETAG 017
Fibre cement panelling	Battens, panels	NBN EN 12467
Fibre cement cladding	Battens, slates or boards	NBN EN 492
Glazing systems	Approved system of glazing	NBN S 23-002, TIN 214 & 221 (BBRI)
High-Pressure Laminate (HPL)	Battens, boards or panels	EN 438-7
Metal sheets	Approved system of metal sheets	NBN EN 14782, NBN EN 14783
Natural slates cladding	Battens, slates	TIN 228 (BBRI), STS 03.6
Plastic façade system	Approved systems of plastic façades	NBN EN 13245-2
Render	Adhesive layer, render	NBN EN 13914-1, EN 13499, TIN 209 (BBRI)
Solar active components	Approved system of solar panelling	IEC 61215, EN 12975/6/7
Solar passive components	Approved system of passive solar façade (e.g. translucent heat insulation)	-
Thermal insulation compound system	Approved system of insulation with render or other mineral covering (e.g. brick strips)	ETAG 004, ETAG 014, TIN 209 (BBRI)
Wood cladding	Battens, shingles or boards	NBN EN 14915, TIN 243 (BBRI)
Wood panelling	Battens, panels	EN 634-1, TIN 243 (BBRI)

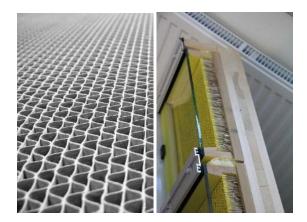


Figure 67. Alveolar approach for passive solar systems. Source: [22] (left) Close-up on the carton board structure; (right) innovative panels fixed on a closed TES.



Figure 68. Lamellar approach for passive solar systems. Source: [23]



(left) Close-up on the wood structure; (right) innovative panels fixed on a closed TES.

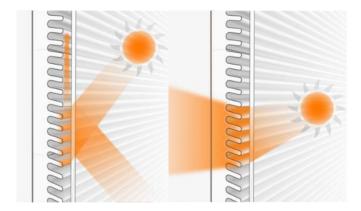


Figure 69. Operation of a wood lamellar structure from a 'passive' solar panel during summer (left) and winter (right). Source: [23]

Table 28. Context parameters to analyse when designing the external layer

CONTEXT: PROJECT DEFINITION



- Goals: Planned environmental quality, planned energy performance, 'Positive energy' goals, Aesthetical aspect sought for
- Climate: Wind loads, driving rains, sun exposure
- Linked design points: 'core' layers of the modules, weather protection

CONTEXT: USEFUL INFORMATION FROM INVESTIGATION





- Building surroundings: shadows, elements that reduce rain exposure, etc.
- Limitations from the urban code

Table 29. Design parameters and attention points when designing the external layer

DESIGN PARAMETERS AND ATTENTION POINTS

- I. Concerning the properties and performance of materials
 - 1. LCA & cost of materials
- 2. Compatibility of materials
- 3. Corrosion resistance & lifespan
- 4. Pollution resistance
- II. Concerning the assembly details
- Fixation system(s)
- 2. Possible need of a rain screen
- 3. Possible need of a support system (substructure, preparatory layer for plaster, ...)
- III. Concerning execution
 - 1. Risks of damage during transport (if the external layer/cladding is implemented off-site)
- IV. Concerning occupants and building use
 - 1. Acceptance of the planned appearance by occupants and neighbours

Table 30. Remarks to support the decision-making when choosing between off-site or on-site implementation of the external layer

REMARKS TO SUPPORT THE DECISION-MAKING: off-site or on-site implementation of external layer?

- The off-site implementation of the external layer requires its protection during transport and storage...
- II. ... But an on-site implementation might require measures to temporally protect the AIMES
- III. Some type of external layers are simply not compatible with transport
- IV. If the AIMES module is delivered with its external cladding, the sealing of joints between panels has to be compatible with a lower accessibility



3.5 Integrated systems

One of the intrinsic benefits of using the AIMES solution is the possibility to totally or partially integrate various building technologies directly at the workshop. What first comes to mind is the windows integration possibility, which is detailed in the next section. But many other building services could be incorporated at various locations within the retrofitted envelope assembly: inside the AIMES modules, on its exterior surface, along the adaptation layer, etc. Here, we will focus on the description of ventilation systems (3.5.2(a)) and the solar technologies (3.5.2(b)).

3.5.1 Windows

(a) Integration possibilities

The prefabrication process offers the possibility of integrating new windows directly into the AIMES façade modules (Figure 70). The total replacement of existing windows should be considered when the existing ones show a low energy efficiency or substantial degradation, which would not be consistent with the performance objectives of a coherent retrofit. With this first solution, the most convenient approach is to adapt the AIMES openings size to the existing ones, the dimensions of which were assessed during the detailed geometrical survey. The enlargement/narrowing of openings can also be considered, generally to improve the day lighting or limit overheating in summer. However, such operations are associated to many additional efforts on-site and limit the possibilities of keeping occupation of the adjacent rooms. It can occur that a previous partial renovation phase resulted in recent and efficient windows. Indeed, those are often the first building components to be renovated, especially when the budgets are tight. A conceivable solution is then to keep the existing windows and to install AIMES modules that do not contain windows. There, it is important to guarantee a good coherence of the old-to-new assembly and the airtightness may be harder to achieve. A fourth option is to add a new windows on the top of the existing one.



Relevant actor(s):

See subtasks

Relevant auestions:

- Which systems could be integrated in the AIMES facade elements?
- How to adequately design these systems and guarantee performance & safety?

(3.5.1)

Relevant actor(s):

- Architect
- AIMES designer
- AIMES producer
- (Experts: EPBD / Building Physics / HVAC & building services / ...)
- (Subcontractor for windows elements)

Relevant questions/themes:

- What is the desired performance of windows (air tightness, thermal transmittance, day lighting)?
- What is the performance of current windows?
- Were the windows replaced recently?
- If new windows are required, what should be their position?
- ٠...



Figure 70. Windows incorporated offsite (Riihimäki)





Figure 71. Conservation of the existing windows and integration of a single-glazed window into the AIMES modules

When designing the windows integration, a particular attention has to be paid to the **position of the window** (old or new) with respect to the plan of the new insulation. This parameter is crucial with respect to thermal bridging, airtightness, fire resistance, and acoustic issues. With simplified models, it is easily shown that the window position has an impact on thermal losses [6] and on the acoustic comfort. If old windows are kept or the new ones placed at the old location, thermal bridge effects can appear (Figure 72). Much information concerning thermal bridges linked to windows position can be found in the document 'Advances in Housing Retrofit' [6].

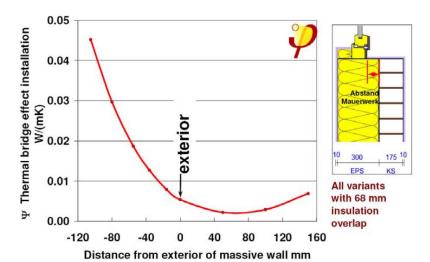


Figure 72. Thermal bridges effect due to the window position. Source: [6]

Several parameters can limit the possible options for the off-site integration of new windows in AIMES modules, e.g. the extra weight caused by highly efficient triple glazing can entail transportability issues. Then, the windows elements can be fixed on the existing wall independently of the mounting of the AIMES elements. In such cases, the installation of windows after the mounting of AIMES modules is more convenient. The installation of new windows frame before the mounting of AIMES modules causes alignment issues as well as unnecessary additional operations and should be considered only in exceptional cases. In most accomplished European case studies for which new windows elements were installed, these were incorporated off-site to benefit from quality assurance and reduce the on-site operations. Note that if some layers of the existing walls are removed and the existing windows kept in place, even for a short periode, the stability of all elements as to be guaranteed during the transitional operations (Figure 73).





Figure 73. Old windows kept in place for a period of time, after the removal of the external layers of the existing walls (Riihimäki, FIN)

(b) Daylight considerations

The daylight analysis constitutes an important stage of windows design. Information can be found in the 'TES Manual' [1].

(c) Additional window equipment

It is commonly accepted that a thoughtless design of the windows can lead to severe overheating problems in summer. However, blinds systems can be integrated directly into the window elements (Figure 74) or inside the AIMES module (Figure 75), generally behind the cladding system. For this second option, high performance insulation materials used locally can guarantee the local coherence of thermal transfers.

The contour of a window is a critical point for air¹⁰ and vapour transfers. Generally, the enhancement of the building airtightness is possible through a meticulous design and implementation of air tight tape around the new window, on the interior side. At the same location, a particular attention needs to be paid to the risk of a vapour transfer from the rooms to the new AIMES elements or to its adaptation zone, which might result in internal condensation. This is especially critical when dealing with open systems, for which the vapour tightness of the injected insulation casing cannot be guaranteed from the factory. When using insulation materials with a high sensitivity to moisture such



Figure 74. Solar blinds integrated in the windows element (<u>Graz</u>, AT)

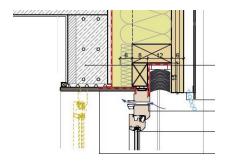


Figure 75. Solar blinds integrated in the AIMES element (<u>Kapfenberg</u>, <u>AT</u>)

69

¹⁰ See the TIN 255 (BBRI)



as cellulosic materials, the risk of failure is even bigger. Appropriate design measures should then guarantee that vapour that enters into the cellulose can escape to the outside.

Table 31. Context parameters to analyse when designing the window elements and their equipment

CONTEXT: PROJECT DEFINITION



- Legal: Requirements in terms of energy performance (U value), requirements in terms of air change rate
- Climate: Number of hours of direct sun exposition
- Goals: Planned performance, planned environmental quality, planned ventilation approach
- Linked design points: 'core' layers of the modules, external layer of the modules, ventilation strategy

CONTEXT: USEFUL INFORMATION FROM INVESTIGATION





- Geometry of openings (reveals and corners)
- Construction of existing windows and sills
- Energy performance of existing windows
- Overheating problem in the existing building
- Daylighting comfort
- Aesthetical constraints
- Shading from surroundings

Table 32. Design parameters and attention points when designing new window elements and their equipment

DESIGN PARAMETERS AND ATTENTION POINTS (scenario: window replacements or window additions)

I. Concerning the properties and performance of materials

- 1. LCA and cost of materials
- Performance of materials
- 3. Corrosion resistance & lifespan of materials

II. Concerning the assembly details

- 1. Frame construction
- Glazing performance
- 3. Weight of windows and impact on the weight of AIMES modules
- 4. Location of technical layers for airtightness and vapour protection
- 5. Possible integrated systems for ventilation (passive or active)
- 6. Impact of the above-mentioned points on the performance of the final assembly:
 - a. U-Value of windows assemblies
 - b. Risks of thermal bridges or hygrothermal problems
 - c. Thermal comfort in rooms
 - d. Visual and thermal comfort for occupants

III. Concerning execution

- 1. Off-site phase
 - a. Correct and easy installation of the airtightness elements
 - b. Protection of windows elements during transport
 - c. Quality assurance
- 2. On-site phase
 - a. Removal of existing windows (Is it planned? Is it possible? Can they be removed from inside?)
 - b. Removal of windows sills (Is it planned? Is it possible?)
 - c. Organisation of the openings enlargement (Is it planned? Is it possible?)
 - d. Protection of windows elements during transport
- e. Correct connection of the airtightness elements to the existing structure

IV. Concerning occupants and building use

- Integration of possible nuisances for occupants in the decision process (e.g. removal of windows from inside)
- 2. Formation of occupants to the use of the windows equipment



3.5.2 Building services

The integration of various building services is possible within AIMES, with both generating devices and routing parts (ducts or cables). In the third reference book published during the *smartTES* project [20], three levels of systems integration for TES are distinguished, and can be extrapolated to any AIMES design (Figure 76):

location of consumption.

AIMES design (Figure 76):

The 'Integrated configuration' concerns small devices used for ventilation or energy generation individually incorporated into single façade modules. The routine from the device to the building is characterised by a

short length and the system is located close to its

- The 'Connected configuration' is typically represented by some ductwork running through several modules. This routine is connected to a larger service facility, which is located far from the location of consumption (e.g. a large mechanical air supply unit)
- The 'Envelope concept' compiles a large range of innovative systems like the solar façade ones presented above (see 3.4.3). A large proportion of the module surface is acting like a reactive or adaptable building skin.

The services integration level can be very high, with combination of ventilation, heating, cooling, water supply, waste water discharge, photovoltaic, solar-heating systems, and other services such as LAN or power lines. Anyway, such conception requires significant additional efforts as the integration of building services has to be considered on the whole-building scale with many secondary implications: the thermal and acoustic insulation performance of the standard module layering has to be guaranteed as well as its fire safety and air tightness. However, this design effort offers to free some indoor volume that would otherwise be occupied by traditional installations.

For cables and ducts installations, a distinction should be made between elements that are fully incorporated to the modules during the off-site assembly and the elements that are completely assembled on-site, e.g. mounted on the existing façade and covered later by the module. To facilitate the categorisation, two main possible locations are distinguished for ducts, cables and pipes installation in the 'TES manual' [1]:

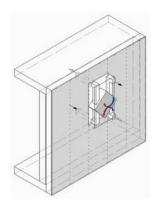
(3.5.2)

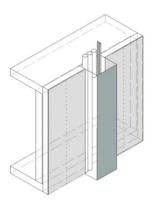
Relevant actor(s):

- Architect
- AIMES designer
- AIMES producer
- Experts: Acoustics, Building Physics, EPBD / HVAC & building services, Fire Safety

Relevant question(s):

- Which service systems devices and ductworks can be integrated in the modules?
- How to guarantee the performance of the new envelope with these implementations?





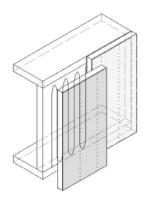


Figure 76. The three levels of system integration distinguished in smartTES (top) 'Integrated'; (middle) 'Connected'; (bottom) 'Envelope Concepts'



- An installation zone (Figure 77): area on the existing façade where pipes or wires are directly fixed. The adaptation layer offers enough space to 'cover' these installations. Can be used for: phone, ethernet, electricity, small plumbing ...
- An installation duct (Figure 78): a separated cavity mainly use for large diameter pipes. Pipes can be directly integrated into the AIMES elements (with some necessary adjustments) or assembled into an independent compartment, which can be installed separately on the existing wall. Can be used for: waste water, rain water, HVAC ...

For cables, which are not sensitive to low temperature, the space located behind the cladding system can also be used. In this document, only the technologies that have a direct impact on the design of AIMES will be discussed.

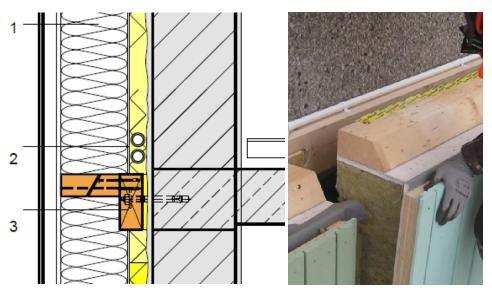


Figure 77. Installation zone (left) Section of an installation zone: (1) TES element; (2) installation zone; (3) substructure at ceiling level. Source: [1] (right) Example in London (UK)

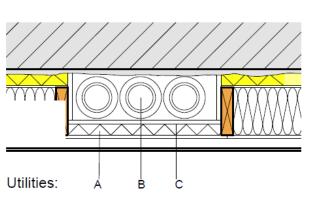




Figure 78. Installation duct (left) Section of an installation duct: (A) insulation; (B) duct work; (C) panels, fire protection. Source: [1]; (right) Example in Kapfenberg (AT)



(a) Ventilation technologies

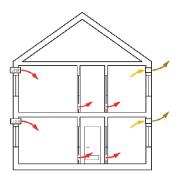
Buildings concerned by a deep envelope refurbishment are often also characterised by aging building services and poor design of ventilation systems, assuming that such exist. High energy performance standards are always associated with goals in terms of air tightness of the building. In consequence, the reshaping of ventilation systems is an essential corollary of the envelope upgrade, to guarantee a hygienic environment for occupants and to avoid the emergence of moisture-related concerns. Using 'AIMES-integrated' and 'AIMES-connected' configurations for systems integration, possibilities exist to re-think the ventilation approach and implement modern centralised or decentralised type D systems (Figure 79).

(3.5.2(a)) Relevant actor(s):

- Architect
- AIMES designer
- AIMES producer
- Experts: EPBD / HVAC
- (Subcontractor for HVAC technologies)

Relevant question(s):

- Which installation is renewed?
- Decentralised ventilation / renovation or complementation of existing centralised system / new centralised system?
- Quid of maintenance issues?
- (Architecturally) incorporated air inlets/outlets?



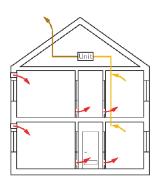


Figure 79. Mechanical ventilation concepts. Source: [20] (left) A decentralised system; (right) a concept based on a centralised system.

A first innovative possibility is to implement decentralised ventilation units. Small air handling units (AHU) with heat recovery (Figure 82) are fitted to horizontal ducts that go through the AIMES façade. Some systems work with two ducts, one for the air inlet and one for the outlet. The ducts generally lie next to each other inside the AIMES element (Figure 80, Figure 81). Other systems work with one duct that can alternate between air suction an expiration. Small apartment can work with a single AHU while bigger ones may require several AHU's (Figure 83). The benefits of these approaches is that no complex duct routine between AIMES modules is required while the amount of indoor interventions is still limited. The ventilation control can also be greatly simplified and the AHU can be associated to various sensors (e.g. humidity, CO₂). A 'ventilation-on-demand' paradigm is easier to achieve. For aesthetical concerns, the air inlets/outlets can be hidden behind the cladding of AIMES (Figure 84). Concerning the downsides of decentralised AHU's, the air filters need to be changed from inside the rooms, thus more likely performed by the occupants. The replacement frequency is generally one to two times a year. It is then crucial that the occupants are informed of that requirement. The acoustics are another important attention point, because the ventilators are located inside the rooms. The air change rates imposed by the Belgian EPBD for air supply or air evacuation (design values, generally close to the maximum flow achievable with the AHU) can provoke acoustic discomfort whereas it may be more acceptable in other countries. However, once the system is designed, installed and correctly configured, the ventilation rated can be adjusted to meet the actual needs of the occupants, possibly resulting in lower ventilation rates.





Figure 82. Decentralised ventilation unit installed on indoor walls surface (left) and without its cover (right). This technology was used In <u>Graz-1 & 2 (AT)</u>

A second possibility is to set up a new centralised ventilation system. A central unit, ideally with heat recovery, is in charge of the air exchanges with the exterior. This unit can be connected to the different rooms through ducts incorporated in AIMES elements. In Riihimäki, the vertical ductwork for supply air was built within the vertical TES modules (Figure 85). 100x120mm and 100x150mm ducts were used and the orientation of TES elements limits the connection efforts between them. In that project, the centralised ventilation system was preferred for its maintenance that does not require the intervention of occupants. In Zürich, the



Figure 80. Decentralised ventilation ducts pre-fitted in the modules.



Figure 81. Holes drilled in the existing walls

horizontal orientation of TES modules caused some hard work for interconnecting the duct network of the centralised ventilation when mounting the AIMES modules. This network was made of ducts directly incorporated in AIMES modules in the factory (**Figure 86**). Another option, which is seen in <u>Kapfenberg</u>, is the implementation of the ductwork in separated casings that are installed on-site separately from the 'standard' TES elements (**Figure 87**).

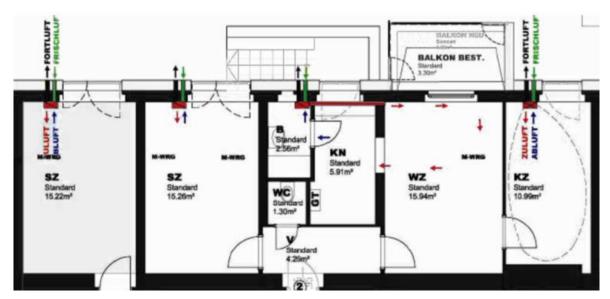


Figure 83. Example of decentralised approach for ventilation. Source: [24]





Figure 84. Apparent air inlet and outlet of decentralised ventilation units (left) or hidden behind glazing (right).

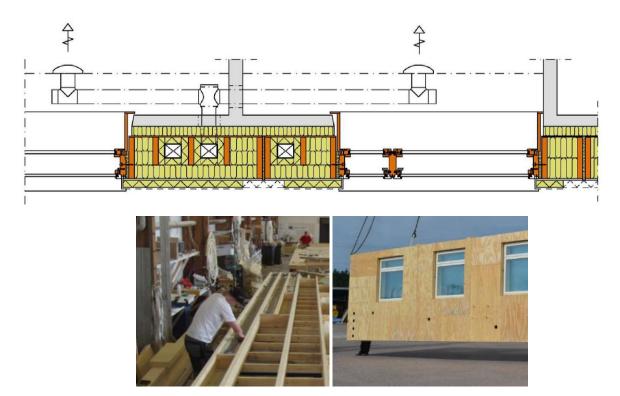


Figure 85. 'TES-connected' system with ventilation ducts incorporated in the new envelope in <u>Riihimäki, FIN</u>. (top) Horizontal section showing constructive details; (bottom-left) incorporation of ducts in the workshop; (bottom-right) holes to connect the ducts to the rooms



Figure 86. 'TES-connected' system with ventilation ducts incorporated in the new envelope in <u>Zurich, CH</u>. (left) Ducts integrated in a special fire-proof casing inside AIMES modules; (right) view of the top of one AIMES element showing the ventilation ducts





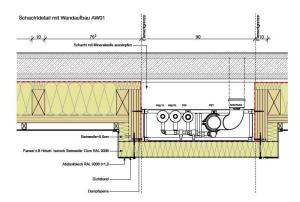


Figure 87. System with ventilation ducts incorporated in specific casing in <u>Kapfenberg</u>, <u>AT</u>: (left) Ducts integrated in a special casing between more classical façade elements; (right) details of conception

Table 33. Context parameters to analyse when designing integrated ventilation systems

CONTEXT: PROJECT DEFINITION



- Legal: Requirements in terms of energy performance (U value), requirements in terms of air change rate, requirements of Fire regulation
- Climate: Pollutants in the air of the surroundings environment
- Goals: Planned performance, planned environmental quality, planned indoor air quality (acceptable levels for the various pollutants)
- Linked design aspects: Windows elements, orientation of volumes, external layer of modules

CONTEXT: USEFUL INFORMATION FROM INVESTIGATION





- Whole building energy performance
- Existing problems linked to ventilation or mould
- Occupation patterns
- Indoor Air Quality (e.g. observed levels of CO₂)
- State of the existing ventilation system(s) + Optimisation potential
- Existing exhaust air duct
- Ceiling height in rooms
- Aesthetical constraints (related to ventilation grates and vents integration on façade)

Table 34. Design parameters and attention points when designing an integrated ventilation system

DESIGN PARAMETERS AND ATTENTION POINTS

OPTION 1: Decentralised approach for ventilation (integrated installations)

- Concerning the properties and performance of materials (ducts, mechanisms, and technical layers)
- 1. LCA and cost of materials
- 2. Durability of airtightness elements

II. Concerning the assembly details

- 1. Fastener systems et construction details
- 2. Required technical layers (sheets, bands, joints) and mechanisms (e.g. fire stops)
- 3. Location of decentralised units and inlets/outlets
- 4. Appearance of inlets/outlets
- . Impact of above-mentioned points on the performance of the final assembly:
- a. Acoustic comfort
- b. Risks of air loops
- c. Risks of thermal bridges

III. Concerning execution

- Off-site phase
 - a. Modalities and equipment linked to pre-fitting of ducts in factory
- On-site phase
 - a. Risks of damage during transport
 - b. Prepare holes in existing façade for fitting of inlets and outlets

IV. Concerning occupants and building use

1. Formation of occupants to the use of the equipment



OPTION 2: Centralised approach for ventilation (connected installation)

- Concerning the properties and performance of materials (ducts and technical layers)
- 1. LCA and cost of materials
- 2. Durability of airtightness elements

II. Concerning the assembly details

- 1. Fastener systems et construction details
- 2. Required technical layers (sheets, bands, joints) and mechanisms (fire stops)
- 3. Connection details between modules
- 4. Clear routine of pipes
- 5. Impact of above-mentioned points on the performance of final assembly:
 - a. Risk of fire vertical propagation through ducts (critical)
- b. Thermal bridges

III. Concerning execution

- 1. Off-site phase
 - a. Modalities and equipment linked to pre-fitting of ducts in factory
- 2. On-site phase
 - a. Risks of damage during transport
 - b. Ducts alignment efforts

V. Concerning occupants and building use

1. Formation of occupants to the use of the equipment

(b) Solar technologies

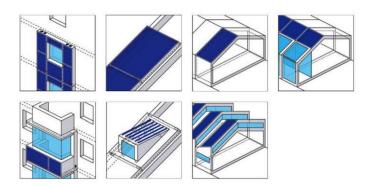


Figure 89. Possible locations for solar panels integration. Source: [8]

The design of AIMES offers many possibilities for the integration of solar technologies (Figure 89 to Figure 91), which can complement systems incorporated on roofs or other special locations (e.g. oriented support attached to the building or installed on its site). Photovoltaic (PV) panels or thermal collectors are easily attached to the exterior face of a façade module. Examples are numerous in the studied cases in Europe. A particular approach used in Graz-2 project is the use of PV panels to produce DHW. The direct current (DC) is directly used to heat water in a specific 'boiler' (Figure 92). This solutions is interesting when thermal collectors would not be a good solution because of the distance between the façade and the rooms that require hot water. Moreover, it does not require any transformation from DC to alternating current.

The use of 'Passive solar panels', as described in **3.4.3**, is another approach for benefitting of solar energy by playing on the

(3.5.2(b)) Relevant actor(s):

- Architect
- AIMES designer
- AIMES producer
- Experts: EPBD / HVAC & solar technologies
- (Subcontractor for solar technologies)

Relevant question(s):

- Is the use of solar technologies on the façade relevant?
- What are the expected benefits?
- Which façade(s) has a good solar exposition?
- Where in the building is DHW needed?



Figure 88. PV panels integrated in AIMES modules (Graz-2, AT)



reduction of heat losses by conduction through the envelope. <u>Graz-1</u> and <u>Graz-2</u> project are two good examples from the study of which the reader will find precious information concerning this technology.

For all solar technologies incorporated off-site in AIMES modules, a particular attention has to be paid to the risk of damage during the transport and manipulation of façade elements. The demountability of systems is also a crucial aspect in order to facilitate a possible replacement in the future.

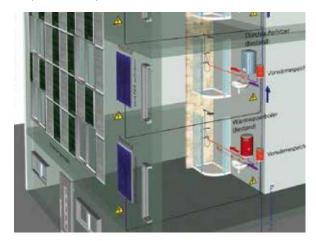


Figure 92. PV panels integrated in AIMES modules used for DHW production (Graz-2, AT)



Figure 90. PV panels integrated in AIMES modules (Pettenbach, AT)



Figure 91. Solar thermal collector

(c) Other services

Additional wired-services such as phone and LAN lines, or power lines can easily be integrated directly inside or behind the façade modules. Some equipment could also be attached on the exterior side of modules. However, all those integration efforts should not be considered with only goals in terms of energy performance and market attractiveness, but also with an assessment of safety and comfort for occupants.

3.6 Mounting layout

3.6.1 Preliminary remarks

This section is intended to describe how the AIMES façade modules could be mounted to the existing structure having in mind that the mounting layout depends to a large extend on the structural aspects and the present-day condition of the building to be retrofitted. This topic covers several design points that are categorised in three main sub-sections:

 The anchorage configuration of AIMES modules and the resulting load transfer (3.6.3)



Relevant actor(s):

- AIMES designer
- AIMES producer
- Experts: Stability
- (Subcontractor for fixation elements)

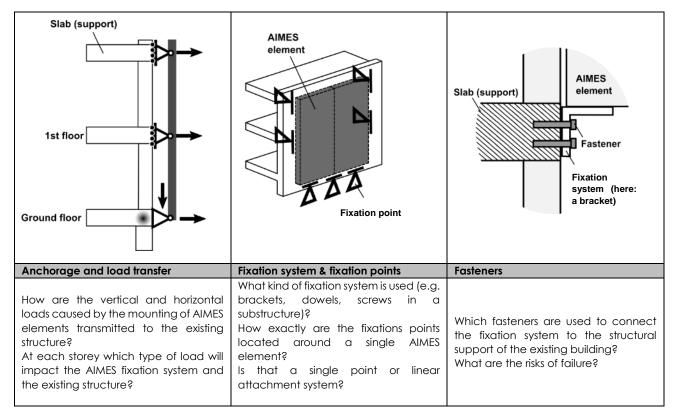
Relevant question(s):

- In which structural elements of the existing building is the AIMES façade to be anchored?
- What is the configuration of this anchorage (where are loads located)?
- Which fixation system is used and what is the distribution of fixation points?
- What kind of fasteners are used?
- What are the structural characteristics of the anchorage support that should be known?



- The type of fixation system and the distribution of fixation points around an AIMES façade module (3.6.4)
- The **fasteners** used to anchor the fixation system to the structure of the existing building (3.6.5)

Table 35. Important design points for elaborating the mounting of AIMES elements



3.6.2 Loads to consider

The AIMES modules are often designed to be self-supporting for reasons of transport, mounting and possibilities of expansion of the building volume. The design of the anchorage configuration, the fixation system (and its fasteners), and the determination of required upgrades to the existing structure should be accomplished considering the following loads and their combination:

- Vertical loads:
 - Permanent weight
 - o Snow and ice
 - (Rain water in case of a new green roof)
- Horizontal loads: wind pressure and suction
- Horizontal and vertical: dimensional tensions from thermal and hygroscopic behaviour
- Non-permanent loads: loads linked to the assembly processes
- (Unusual loads during the transport of the module)

Additional information concerning these definitions can be found in Eurocode 0 - 'Basis of structural design' and Eurocode 1 - 'Basis of design and actions on structures'. If no new foundation system is implemented, the façade modules (and possibly roof modules) will necessarily cause some noticeable stresses on the existing structure which have to be rigorously studied (see **2.3.5**). For a timber-based AIMES module with a U-value of



0.13 W/m²K, an additional weight of about 85 kg/m² of façade can be expected. Regarding the loads and the planned fixation system, two cases are possible: either the existing structure is able to bear the loads of the new envelope, either not. When loads are planned to be directly transmitted to the existing walls, the stability survey should also provide information concerning the load-bearing capacity of the latter because of the additional and eccentric weight.

3.6.3 Anchorage configuration and load transfer

The existing structure and its condition have a great influence on the choice of a load transfer/anchorage configuration. As mentioned in the 'TES manual' [1], the starting point of the structural conception is always the building plans and the original structural calculation, if such are available. An additional on-site survey will always provide precious information (actual structural performance due to possible deterioration of the load-bearing elements).

Three types of load transfer configurations are possible for AIMES elements installed on top of existing walls with the anchorage located in the floor slabs (the most frequent anchorage location):

- Standing configuration (with single-storey span, 'articulated single-storey span', or multi-storey span of AIMES modules): modules are self-standing and the vertical loads are collected either at the base of the existing construction (on existing foundation, new foundation or large support element) or at each storey ceiling through anchorage elements. The 'articulated single-storey' approach designates a system where all modules are stacked horizontally on top of each other, the vertical loads being collected at building base. A substructure often acts as coupling element between the existing slabs and the AIMES module (Figure 93) but only horizontal loads are supported by floor slabs above the ground floor. This system is problematic for medium and high-rise building under the Belgian Fire Safety regulation.
- **Top-suspended configuration** (with single-storey or multi-storey span of AIMES modules): modules are 'hung' from their top side. Vertical loads are collected either at each storey ceiling either on top of the building depending if the modules are single- or multi-storey spanned.
 - → (This system is currently not well-spread and will not be further discussed here)
- **Distributed configuration** (with single-storey or multi-storey span of AIMES modules): modules are 'cladded' on the existing structure, the vertical loads are distributed equally around each AIMES element. A temporary structure can be used to hold the module in place before attaching it.

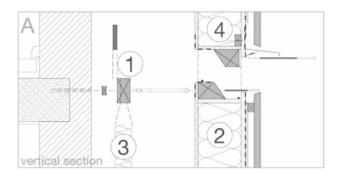


Figure 93. Coupling role of the substructure in composed beam configuration. Source: [25]

The analysis of realised cases shows that only standing and distributed anchorage configurations are well represented. **Figure 94** provides a visual illustration of the various configurations found in European cases, with the different sub-categories. Some realisation details are provided in section **3.6.9**.



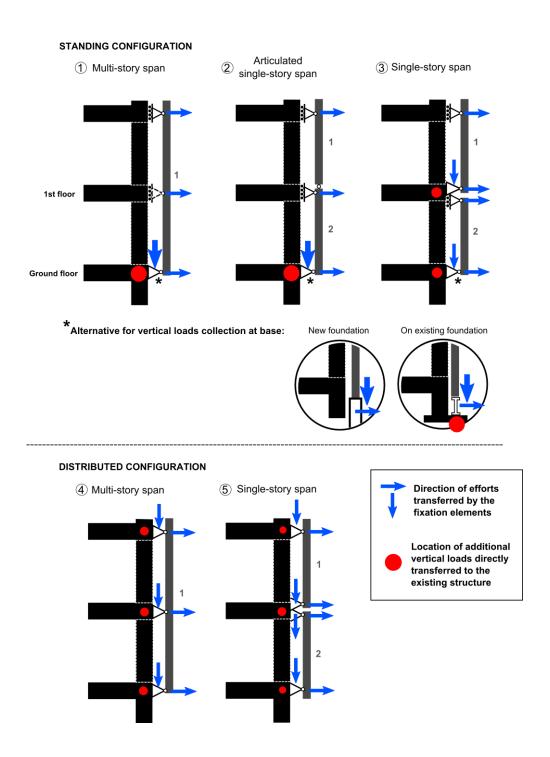


Figure 94. Frequent anchorage configurations

For the frequent standing configuration, several options are commonly used to transfer the vertical loads at the bottom of the building. The first possible option consists in using the existing foundation without any reinforcement. It requires that the foundation has a reserve of load-bearing capacity. The second option is to reinforce the foundation system. The third option is to implement a new foundation able to support the prefabricated envelope system. It is also relevant when a large amount of new loads results from the retrofit (e.g. a new storey). A very good illustration of the many possibilities is found in the second book of the smartTES project [19] and was redrawn here (Figure 95). With the 'distributed anchorage', the vertical loads



will reach the foundation through the existing walls. It may also require reinforcement of the foundation elements depending on the results of the structural survey.

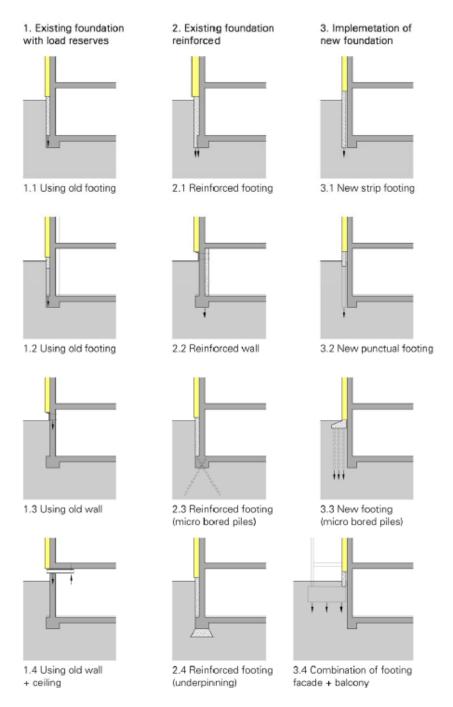


Figure 95. Overview of various solutions for the loads transfer at the bottom of a building for standing AIMES. Source: [19]

3.6.4 Distribution and types of fixation elements around an AIMES façade module

The mounting of AIMES façade is defined by the configuration of its anchorage in the existing building but also by the type of fixation system. Two categories of fixation systems can be inventoried: single-point or linear, which can be horizontal or vertical (Figure 96). Single-point fixation systems mainly include brackets, dowels, or special hinge systems (e.g. Berlin (DE) and Pettenbach (AT) case studies). A linear fixation is typically achieved by using a wood-substructure on which the AIMES modules are screwed, or by implementing a sill



at the base of the building (e.g. Riihimäki (FIN) and Roosendaal (NL) case studies). Globally, there is a large diversity of fixation possibilities and several types may produce the same final load transfer to the existing structure. Also, in the same building, each type of module can have a different fixation systems (depending on its location on the building), and a single module can combine single-point and linear fixations on its different sides.

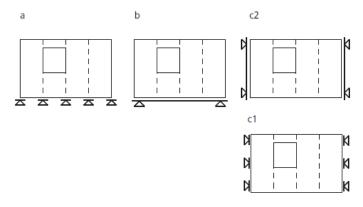


Figure 96. Nomenclature of fixation possibilities: (a) Horizontal single-point support; (b) horizontal linear support; (c2) vertical linear support; (c1) vertical punctiform support. Source: [1]

Table 36 provides an overview of frequent fixation possibilities for a timber AIMES façade, for the different anchorage/load transfer configurations defined in the previous section. **Figure 97** illustrates these variations with some examples for the 'standing – multi-storey' anchorage configuration (vertical AIMES elements).

Table 36. Overview of frequent fixation systems depending on the anchorage configuration (for anchorage in floor slabs)

ANCHORAGE CONFIGURATION	STANDING – MULTI-STOREY SPAN	STANDING – ARTICULATED SINGLE-STOREY SPAN ¹	STANDING – SINGLE-STOREY SPAN	DISTRIBUTED – MULTI-STOREY SPAN	DISTRIBUTED – SINGLE-STOREY SPAN
ORIENTATION OF AIMES MODULES	Vertical	Horizontal	Horizontal	Vertical	Horizontal
FIXATION OF THE BOTTOM AT GROUND AIMES LEVEL MODULE	Horizontal single-point support (heavy duty brackets) or Horizontal Linear support (Sill)	Horizontal single- point support (heavy duty brackets) or Horizontal linear support (Sill)	Horizontal single- point support (heavy duty brackets) or Horizontal linear support (Sill)	Single-point support (dowels or special hinge systems)	Single-point support (dowels or special hinge systems)
IN STOREY SLAB	X	Horizontal linear support (screws in the substructure)	Horizontal single- point support (heavy duty brackets)	X	Horizontal single-point support (dowels or special hinge systems)
FIXATION OF THE TOP- PART OF AN AIMES FAÇADE MODULE (IN STOREY SLAB OR TOP FLOOR LEVEL)	Horizontal single-point support on top of the AIMES module (brackets) or Vertical single-point support on the edges of the AIMES module (brackets) or Horizontal linear support on top of the AIMES module (screws in an horizontal substructure) or Vertical linear support on the edge of the AIMES module (screws in an vertical substructure)	Horizontal single- point support on top of the AIMES module (brackets fixed to the building or a substructure / screws in an horizontal substructure) And/or Vertical linear support (screws in an vertical substructure)	Horizontal single- point support on top of the AIMES module (brackets) or Horizontal linear support on top of the AIMES module (screws in an horizontal substructure)	Single-point support (dowels or special hinge systems)	Single-point support (dowels or special hinge systems)



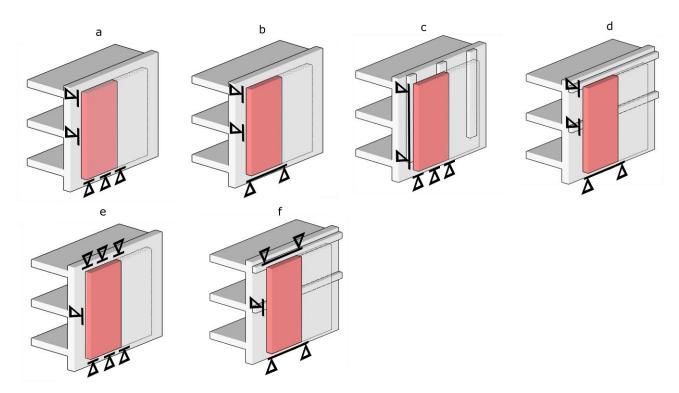


Figure 97. Illustration of the diversity of fixation system and fixation points. Some examples for the 'standing continuous beam':

- (a) No substructure, horizontal single-point support at the bottom (e.g. large brackets) and vertical single-point support on the edge of AIMES modules (e.g. small brackets)
- (b) No substructure, horizontal linear support at the bottom (e.g. sill beam on a new foundation) and vertical single-point support on the edge of AIMES modules (e.g. small brackets)
- (c) Vertical substructure, horizontal single-point support at the bottom (e.g. large brackets) and linear support on the edge of AIMES modules (screwed to the substructure)
- (d) Horizontal substructure, horizontal linear support at the bottom (e.g. sill beam on a new foundation) and vertical single-point support on the edge of AIMES modules (e.g. small brackets). Similar to example b but with the advantages of a substructure (reduced alignment efforts during mounting operations)
- (e) No substructure, horizontal single-point support at the bottom (e.g. large brackets), horizontal single-point support on the top of AIMES modules (e.g. small brackets), and additional single-point support on the edge of the module.
- (f) Horizontal substructure, horizontal linear support at the bottom (e.g. sill beam on a new foundation), horizontal linear support on the top of AIMES modules (screwed to the substructure), and additional single-point support on the edge of the module

3.6.5 Fasteners in the structure of the existing building

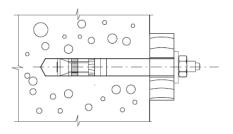
For all that concerns fixation systems and fasteners, most manufacturers have very high-performance computational software. In all cases, it is advisable to test fasteners on-site because of the large variations in the quality of the existing substrates. It should also be constantly checked if the total load on the anchor element can be transferred to the existing structure without a risk of failure. If necessary, the anchorage configuration can be modified.

(a) For anchorage in solid concrete

The type of fastener used to anchor the AIMES module in the existing building will always depend on the deterioration level of the support (generally floor slabs). Usually, anchors are embedded in concrete



structures. Therefore, it is important to know the quality of the hosting concrete. Relevant information can be found in Eurocode 2 – 'Design of concrete structures - Part 4: Design of fastenings for use in concrete' [26] and in the 'ETAG 001 – Metal anchors for use in concrete' [27]. Examples of fasteners for anchorage in concrete are provided in Figure 98 to Figure 100.



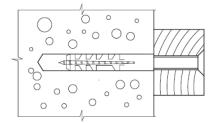
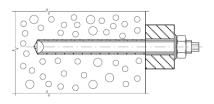
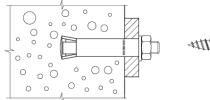


Figure 98. Friction fasteners





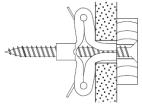


Figure 99. Chemically bonded fastener

Figure 100. Mechanical locking fasteners

(b) For anchorage in masonry

Usually, masonry walls are hollow elements (in concrete or in clay material). When fasteners are placed into the hollow element, a part of the anchor mechanism will not be in contact with the support. To counter this lack of adherence, a matrix can be locally poured into the masonry, which creates an embedded anchor that can be calculated the same way than an anchor placed in a filled element. In all cases, it seems interesting to design the fasteners in masonry with many smaller anchors rather than with a few strong attachment points.

3.6.6 Summary tables

Table 37. Context parameters to analyse when designing the anchorage configuration and the fixation elements

Legal: requirements in terms of stability safety Actions: Weight of new elements, wind loads, snow loads, existing loads (roof, walls, slabs, etc.) Design choices: Restored for reusing, replaced with new ones, left with no restoration for retrofitting Goals: Dimensions of modules, orientation of modules, module substructures, module anchorages INVESTIGATION ON EXISTING BUILDING Type of structure of the existing building Type of slab, type of walls Position, dimensions and characteristics (e.g. reinforcement) of the structural elements Accessibility to structural elements (including hidden elements) Quality and condition of structural elements



Table 38. Common design parameters and specific attention points when designing the anchorage configuration and the fixation elements

DESIGN PARAMETERS AND ATTENTION POINTS

- I. Concerning the properties and performance of materials
 - 1. Nature of the fixation elements and fasteners (LCA, cost)
- 2. Performance of the fixation elements and fasteners (mechanical performance, thermal performance, etc.)
- II. Concerning the assembly details
 - 1. Types, location and quantity of the fixation points
 - 2. Type location and quantity of the fasteners
 - 3. Use of a substructure?
 - 4. Awareness of the types of failures for the various parts of the fixation assembly

III. Concerning execution

- 1. Off-site phase
 - a. Structural integrity of the AIMES elements during transport
- 2. On-site phase
 - a. Schedule of operations
 - b. Equipment for the lifting and alignment of modules
 - c. Temporary support until final fixation (with need of scaffoldings)

REMARKS

A new foundation to support AIMES modules will take all vertical loads

No need to verify the fastener failure due to vertical loads or momentum. Although a new foundation system is an expensive solution

3.6.7 Remarks concerning vertical and horizontal extensions

Horizontal and vertical space extensions require more complex decisions concerning the load transfer configuration. There exist several types of extensions, and the connection of new structures to the existing building can take many forms. An example of this complexity is provided in Figure 101. In this document, these points are not detailed but additional information can be found in the second book produced in *smartTES* project [19].

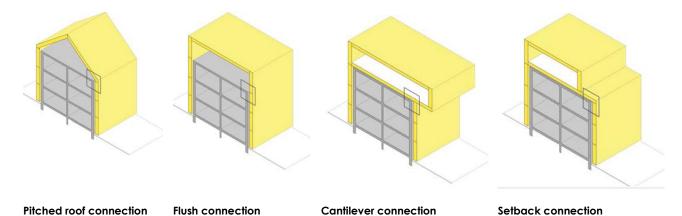


Figure 101. Typology of vertical extensions with great variations in the connection to the existing building. Source: [19]

3.6.8 Modules chaining

The connection between individual modules can be made according to three different schemes (Figure 102):

- Flush joint
- Rebate joint
- Tongue-in-groove joint



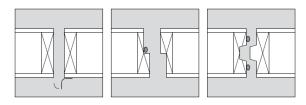


Figure 102. Types of elements joints with examples of air-proofing (left) Flush joint; (middle) rebate joint; (right) tongue-in-groove joint. Source: [1]

The airtightness of the AIMES chain is crucial to guarantee the energy efficiency (by limiting the wind penetration – see **4.1.2(d)**), the sound performance, the weather and protection, and the fire safety. As a general rule, butt-to-butt mounting without any exterior sealing is not satisfactory. Quality control phases of AIMES modules chain (with associated joints) should be planned. This point is essential for the building commissioning (see **6.2**).



Figure 103. Rebate joint with a rubber lip for airtightness (London, UK)

3.6.9 Examples in European case studies

(a) Standing configuration – multi-storey span

This anchorage configuration is the most frequent for vertical modules. In the retrofitting of a large apartment block in <u>Kapfenberg (AT)</u>, the existing walls were kept and a wood attachment substructure (horizontal) is fixed to the ceiling slab edges (**Figure 104**). Small brackets serve to fix the large vertical modules laterally to the substructure (punctiform attachment). Vertical loads are collected at the base of the building on a new foundation. In <u>Riihimäki (FIN)</u>, the outer layers of the existing prefabricated sandwich walls were removed previous to the installation of a similar attachment substructure (**Figure 105**). An additional foundation was also installed before mounting the modules to bear all the new vertical loads.

Terraced houses were refurbished with prefabricated elements in <u>Roosendaal (NL)</u>. In that project, the outer leaf of the existing cavity walls was demolished (cladding bricks). An extension of the foundation was implemented for supporting the new façade modules.



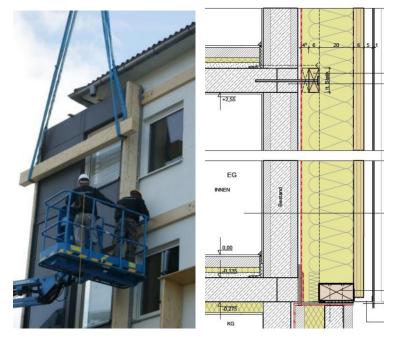


Figure 104. <u>Kapfenbera</u> project: Mounting layout overview (left) Installation of AIMES elements with attachment on a substructure (right) Details of anchorage with a new foundation at building base

(b) Standing configuration – articulated single-storey span

The standing construction with an 'articulated' configuration is well represented abroad for the horizontal module layout. Modules lie on each other (**Figure 106**), generally through tongue-in-groove joints. In both projects carried out in <u>Graz (AT)</u>, large metallic brackets were fixed at the bottom of the existing building







Figure 105. <u>Riihimäki</u> (FIN) project: load-bearing system overview (top) New footing at building base (middle) Horizontal attachment substructure (bottom) Installation of AIMES elements.

to collect vertical loads (**Figure 107**) and a vertical wood substructure allows to fix the modules. Mineral wool is placed between the substructure studs to ensure an air-free levelling layer and additional XPS insulation is placed in front of the base brackets to meet the Fire Safety regulations (**Figure 108**). In the <u>Augsburg</u> case, an additional foundation was poured to support the modules and a horizontal attachment substructure is bolted to the building floor slabs (**Figure 109**). A rebate joint system ensures the modules chaining. The same types of substructure and modules chaining are found in the <u>London (UK)</u> project, but high strength cellular concrete blocks lying on large steel brackets are used for the base support (**Figure 110**).

Due to fire safety regulations in Belgium, articulated single-storey span mounting configuration should be avoided for medium and high rise building; at least, it will require special derogations. Indeed the integrity of the façade system needs to be guaranteed even if one module is struck by fire. It is difficult here, as modules are lying on top of each other.





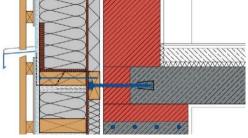


Figure 109. <u>Augsburg (DE)</u>: attachment of horizontal modules to a substructure:

(top-left) Installation of one AIMES element on top of another (top-right) View on the tongue-in-groove joint (bottom) Details of the anchorage in ceiling slabs.



Figure 110. London (UK) project:

(left) A rebate joint system similar to Augsburg (DE) case

(right) The vertical loads are collected at building base with large
brackets and cellular concrete blocks.

(c) Standing configuration – single-storey span

This load-bearing configuration is less frequent but **compatible** with fire safety regulations for medium and high rise buildings in Belgium. The vertical loads are supported at each storey. In other words, each module is supported independently, which limits risks of chain collapsing. This technique was used for the retrofit of a school in <u>Buchloe (DE)</u> where large metallic brackets were fixed on the edge of each floor slab (**Figure 111**).

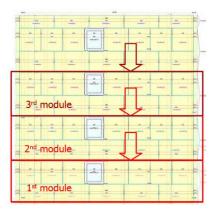


Figure 106. Load transfer in a composed beam system: each horizontal AIMES panel lies on top of the one beneath





Figure 107. Mounting layout used in Graz-1 (AT) (top) Vertical attachment substructure; (bottom) large brackets to collect loads at base.



Figure 108. Bottom XPS insulation in front of the large brackets used to collect loads at building base (<u>Graz-2</u>,



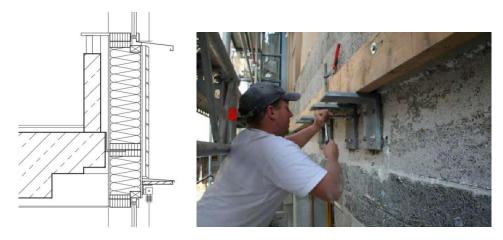


Figure 111. Buchloe (DE) project: large brackets used to collect vertical loads at each storey

(d) Distributed configuration – multi-storey span

The particularity of this configuration for vertical modules lies in the use of a **distributed system of identical anchorage elements at the location of ceiling edges**: the vertical loads are symmetrically distributed in structural slabs.

Such 'cladded' construction system was used in <u>Berlin project</u> where large dowels pass through the module wood structure and are sealed in the structural concrete slabs of the building (**Figure 112**). A large wooden beam is used below the vertical modules to optimise their alignment. The modules have a three-storey span, due to transportability limitations.





Figure 112. <u>Berlin (DE)</u>: Mounting system overview (left) Assembly of AIMES elements (right) Anchorage principle with a linear and horizontal fixation scheme with dowels

(e) Distributed configuration – single-storey span

This anchorage configuration is found in the <u>Pettenbach (AT)</u> project. Hook-in fixation elements are used to collect the horizontal and vertical loads resulting from the installation of the open TES system. The fixation system is separated in two parts: one is anchored in the structure of the existing building, the other is installed



on the back of the AIMES element (Figure 113). During assembly, the two parts are put together through a 'sliding' movement (Figure 114).

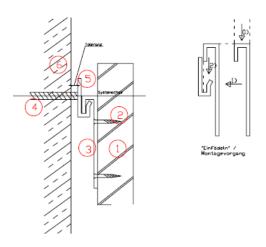


Figure 114. Hook in system used in <u>Pettenbach</u>

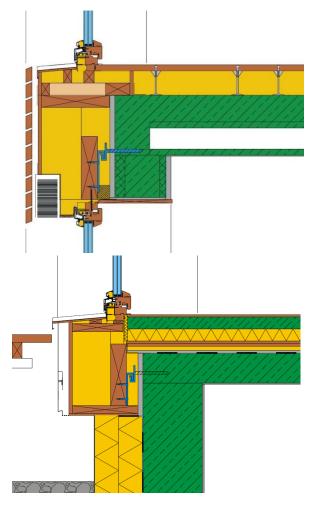


Figure 115. Details of the AIMES installation (<u>Pettenbach, AT</u>)
(left) On the first-storey ceiling
(right) At building base





Figure 113. Hook in system used in Pettenbach
(top) Hook in system assembled through a sliding motion
(bottom) View showing the hooks elements installed on an AIMES module



4. Building Physics & Fire Safety

4.1 AIMES: hygrothermal behaviour

4.1.1 Actions in design phase

As can be seen in the preceding sections, the design of prefabricated façade elements requests to pay a constant attention to considerations of building physics. The hygrothermal performance of the facade resulting from technical choices is a critical point to be considered. In the document 'SmartTES Book 4 - Building Physics' [28], a general procedure is proposed to determine the actions needed to integrate these concepts. The latter was adapted and is illustrated in **Figure 116**.

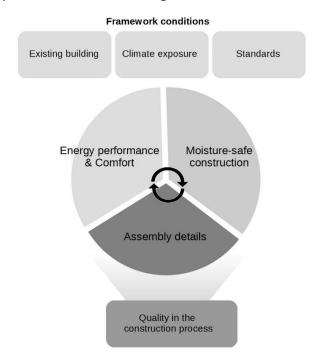


Figure 116. Chart diagram for the assessment of climate exposure and actions in design: topics to assess and evaluate

First, there is a set of preconditions (or context/framework conditions) that will define the necessary and possible actions in the hygrothermal design. These preconditions were identified during the investigation phase. The existing building is of course the first of these preconditions. Its architectural features and its state, which must be accurately studied (see **Chapter 2**), will determine all the measures necessary to meet the current standards requirements. These standards form the second framework element in the design process. In some cases, one may want to exceed the level of requirements of the normative framework as required by the client. Finally, the climate to which the building is subject or any specific exposure will influence the hygrothermal design.

The design tasks linked to hygrothermal performance are grouped under three main categories:

- Energy performance and comfort. This task covers the following operations:
 - o Define the requirements in terms of energy efficiency
 - Design the façade modules to comply with these requirements
 - Adequately document the energy characteristics of the materials and systems that are planned to be used



- Compute the energy performance of the retrofitted building
- Moisture safe construction. During this task, it is necessary to:
 - Document the hygrothermal properties of the materials present in the existing building and the ones planned to be implemented in the new façade
 - Document the solutions chosen to avoid damage linked to moisture (wind-screens, vapour barriers, etc.)
 - o In case of doubt, perform 1D or 2D simulations of envelope elements (e.g. internal and surface condensation risks)
- Assembly details. During this task, the various constructive details should be studied and continuously improved until the energy performance and moisture-safe requirements are guaranteed. The following elements are critical
 - The interface between the existing walls and the new modules; constructive details of the adaptation layer and fixation systems of façade modules
 - o Rain waterproofing elements
 - o Air and wind tightness elements around windows and between modules
 - Details linked to the integration of building services (ducts, wires, etc.)

Besides this, a global task of 'quality' is necessary to **ensure that the chosen solutions are implemented in a good manner during the construction phase** and that the planned performance will eventually be achieved. In this context, the construction details related to the airtightness and moisture safety are particularly critical. The description of these details must be provided in a clear way.

4.1.2 Energy performance and comfort

(a) Basic requirements

A building must be designed to provide a secure and comfortable space for the occupant, throughout the seasons, while keeping the use of non-renewable resources to its minimum. The strategy for implementing a low energy design passes through the following points:

- Reducing heat losses
 - Improving building envelope
 - Reduce transmission losses with an improved U-value
 - Fight against thermal bridges
 - Improve air tightness
 - Improve building compactness
 - Recover heat that is lost through ventilation
- Reducing cooling needs
 - Prevent overheating
 - Benefit from thermal inertia
- Reducing electricity consumption
 - Energy efficient lighting and use of daylight
 - o Energy efficient equipment
- Change energy sources
 - o Smart use of direct solar energy through windows
 - Passive and active solar technologies
 - Biofuels
 - Heat pumps



(b) U-value

The design strategies to reduce the heat losses by conduction are well known. Applying a new façade on top of the existing one is an opportunity for **improving the insulation factor of both wall and windows**. As described above (see **3.4** and **3.5.1**), the choice of the layers composing the AIMES elements and the choices of keeping or replacing the existing windows will determine a K-level of the retrofitted envelope. For opaque surfaces, the limit U-values fixed by the EPBD will require a certain thickness for the insulation layer depending on the performance of the existing wall and the chosen material for AIMES modules insulation. Insulation thickness of 300mm or more are not rare to reach passive levels. As proven in the case studies, AIMES solution potentially offers a very high thermal efficiency.



Figure 117. Through-hole mounting method presenting a higher risk of thermal bridges (Berlin, DE)

(c) Thermal bridges

There are three types of thermal bridges: constructional, material, and geometric. These can have an impact on thermal performance, directly be shortcutting thermal paths, but also through vapour condensation effects, which can deteriorate the physical behaviour of materials. TES approach for AIMES elements offers one big advantage: it uses wood as structural material, which is characterised by a relatively low thermal conductivity. Thermal bridges due to a timber structure are thus very limited. The metallic fixation element, like brackets or dowels, are most of the time confined in the warm zone. In <u>Berlin</u> project, large dowels with a through-hole mounting method were used (Figure 117), which presents higher risks of thermal bridges. However, such thermal bridges will cause internal condensation only if no measure is foreseen to stop vapour from entering the TES elements.

We recall that the AIMES approach offers possibilities to get rid of thermal bridges on the existing façade, thanks to its 'enclosing' nature. This is also true for balconies, which can be included in the heated space. Thermal simulations (Figure 118) will help the designer to localise and characterise existing thermal bridge and avoid the formation of new ones, which can appear by contrast between the highly insulated new façade and the poor construction of old assemblies. Models developed during the investigation phase can be used again for this assessment procedure (e.g. with Kobra software developed by the BBRI). Window and door elements are a 'fertile ground' for the creation of thermal bridges and should therefore be meticulously studied. Indeed, as mentioned in 3.5.1, the position of these element on the plane are critical. Windows generally represent a larger post of expense relatively to doors, the replacement of which

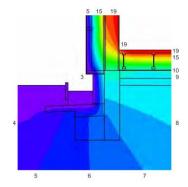


Figure 118. Example of a thermal simulation to evaluate the risk of thermal bridges (<u>Pettenbach</u>, <u>AT</u>)

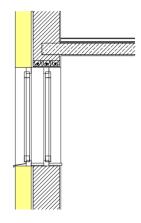


Figure 119. Example of a configuration where the old window is kept but the AIMES element comes with an additional window. Source: [1]



may not be a problem. Keeping old windows can result in the formation of geometrical thermal bridges and the choice of a 'double window' configuration can help to solve this issue (**Figure 119**).

(d) Air tightness and wind protection

Insulation and air tightness combined to thoughtful ventilation strategies are essential properties of a highly efficient building envelope. Whereas the insulation refers to the ability of the envelope to limit the heat losses by thermal conduction, the air tightness translates the amount of air that can enter or leave the building directly through the envelope under a specific differential air pressure. It should be noted that a well-insulated building is not necessarily airtight. An efficient air tightness design allows to:

- Improve the building energy efficiency by ensuring an optimal control of air infiltration/exfiltration
- Improve the occupants' comfort by reducing the indoor air draughts
- Avoid moist and warm air from a room to quickly penetrate the structure, causing internal condensation damage

However, enhancing the air tightness of a building without a thoughtful analysis of the whole-building behaviour can lead to severe issues such as indoor surface condensation or insufficient indoor air quality. The humidity and pollutants created in the building by the occupants and their activities must find a way out. Here intervenes the properly-designed ventilation system (3.5.2(a)) In order to evaluate the air tightness of a building, a pressurisation test can be performed according to NBN EN 13829, also referred to as the 'blower door test'. For new constructions, it is generally recommended that this test is performed after installation of the insulation, but before placing finishes in order to make possible corrections to leaks. If well designed, the AIMES method provides the opportunity to greatly improve the airtightness of the building, by its 'wrapping' nature. If the interior finishes are in good condition, the efforts for airtightness improvement will be located around windows where special tape can be used. The performance of a building to its airtightness viewpoint is assessed by the leakage rate at 50Pa.

Another crucial issue related to movement of air is the risk of wind penetration through the new envelope elements, which would result in a drastic diminution of their performance¹¹. If no technical measure



Figure 120. Tape used for airtightness around windows, <u>Berlin</u> (DE)



Figure 121. Tape used for wind protection to avoid the penetration of exterior air between the exterior panels of the AIMES element, Roosendaal (NL)



Figure 122. Rubber lips and tape to limit wind penetration between modules (London, UK)

Useful standards/documents

- (BE) NBN D50-001
- (BE-EU) NBN EN 13829
- TIN 255 (BBRI)

¹¹ Risks of thermal bridges and internal condensation



is foreseen for wind protection, a building made airtight by means of AIMES modules (low air leakages from the inside) can still suffer from reduced performance due to penetration of exterior air from the outside through the modules and/or through the junctions between modules. Cold air will then reach the space between the old walls and the AIMES elements. A 'wind barrier' approach is thus essential and will be focused on limiting the voids between AIMES modules. This can be achieved by using rubber lips within groove-and-tongue connections of modules, tape, or a combination of both approaches if necessary. **Much information related to air tightness can be found in the TIN 255 (BBRI)**.

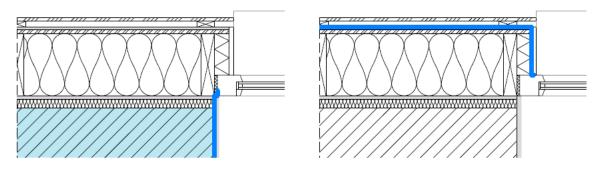


Figure 123. Air tightness (left) and wind-proofing (right). Source: [29]

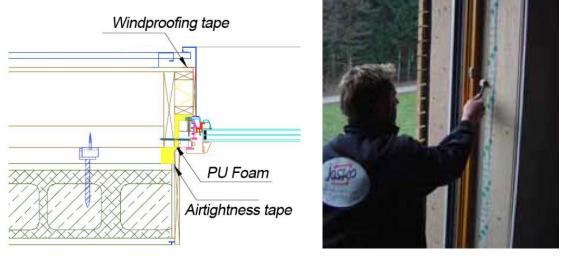


Figure 124. Air tightness and wind proofing in Pettenbach (AT)

(e) Reducing cooling needs

There exist several ways of reducing the risks of overheating in summer with an appropriate AIMES design (e.g. integration of solar blinds). Even if the investigation phase did not reveal any problems in the existing building, it is crucial to realise that **new overheating problems can appear due to the high thermal performance of the AIMES envelope**. Numerical simulations, used in the design phase, should help the development team to take adequate decisions and solutions in order to ensure a good summer comfort for occupants.

4.1.3 Moisture-safe design

The presence of moisture in the building materials can cause an accelerated degradation of those (erosion or decay from freeze-thaw cycles, biodegradation, salt efflorescence, etc.) as well as a serious attack on their thermal, acoustic and structural performance. Moreover, the presence of humidity inside or on the surface of



walls can cause hygienic problems. It is therefore necessary to include several moisture protection concepts in the design of the prefabricated facade modules.

The six major causes of presence of water in a building material are (1) the construction water¹²; (2) the direct penetration by absorption under the effects of heavy rain or due to leakages; (3) the capillary absorption by direct contact with a moist medium; (4) the internal condensation; (5) the surface condensation; (6) the hygroscopicity of salts. Each of these phenomena can be avoided by taking appropriate measures. First, the installation of a new envelope must in no case be taken before the cause of existing problems is identified and resolved. Some problems can be solved by the new 'skin' of the building, as typically leakage problems, while many others will require independent measures prior to the mounting of modules, or the risk of accelerating problems is real.

If the existing problems were taken cared off, and a sufficient time allowed for the building to dry, some AIMES design points that should be assessed in order to guarantee the moisture safety are mentioned in **Table 39**.



Figure 125. An example of moisture-safe design: moisture barrier between the footing and the base sill of the wall

Useful standards/documents

TIN 252 (BBRI)

Table 39. Attention points to guarantee moisture safety: potential risks and associated solutions

Risks	Attention points			
Construction water (in AIMES modules)	 Plan a proper weather protection of modules during transport, on-site storage and mounting phases Allow sufficient drying time if cast materials are used (e.g. Lime-Hemp) 			
Internal condensation (in AIMES modules)	 Moisture from indoor air should not be able to enter the AIMES modules Avoid air shortcuts that bring cold exterior air inside the walls Avoid thermal bridges Provide a vapour membrane if necessary Guarantee a good conception of wind protection between elements (joints, tape, etc.) 			
Internal condensation in integrated ducts	Avoid thermal bridges, provide good peripheral insulation of ducts			
Surface condensation	 Avoid thermal bridges Provide a good conception of wind protection around openings Provide a good conception of the ventilation systems, especially if the airtightness is drastically increased 			
Capillary rise at the base of the building	 Cure capillary absorption phenomena in the existing walls Break the capillary continuity between AIMES materials and the soil (e.g. moisture barrier between the lower walls and the AIMES modules) 			
Absorption from moisture projections at the bottom of the building	 Provide a good design for the footing Provide a higher footing if necessary Provide membranes with good details 			
Absorption of water from driving rain on exterior surface	 Provide a good design for the cladding system Provide an adequate rain screen if necessary (e.g. for openwork cladding) Ensure drying possibilities from outside surfaces 			
Absorption of water from driving rain around windows or doors openings	Provide a good design for windows and doors, with a good evacuation of incoming rain water and protection to avoid penetration			

 $^{^{12}}$ Including the water accumulated during the on-site operations due to improper weather protection



4.2 AIMES and acoustics: basic requirements

The new exterior walls have to fulfil criteria of sound protection for airborne as well as structure-borne sounds. Those can arise from outside (street noise, industries, rain, etc.) and from inside the building (other apartments, building systems, etc.). It is fundamental to study all potential sources of noise. When designing an AIMES solution with focus only on the exterior acoustic insulation, it can ultimately result in increasing the discomfort for occupants. Indeed, noises that originate from inside the building will appear louder than before the retrofit.

The airborne sound transmission is avoided by implementing an adequate caulking of gaps and joints [1] whereas the structure-born sound transmission is avoided by decoupling constructive elements. Structure-borne sounds mainly arise by impact or by the operation of built-in parts. The theoretical solution is simple: the possible transmission paths have to be de-coupled. The entire façade composition should be considered, from the inner to the outer surface, and including the existing structure.

As for thermal transmission, the horizontal position of the window within main insulation layer of the module also plays a critical role in the final performance. If old windows are kept and an AIMES façade is applied on top of the existing wall, there exists a risk of drastically decreasing the acoustic performance that would be obtained with a good alignment.

4.3 AIMES and Fire safety: basic requirements

4.3.1 Principles

(a) Royal Decree

Considerations of fire safety are closely related to the building size. In this matter, the Royal Decree (RD) of 7 July 1994 and its amendments, the Royal Decree of April 4, 1996, December 18, 1996, December 19, 1997, April 4, 2003, June 13, 2007, March 1, 2009 and July 12, 2012 constitute a reference framework. For renovation, however, it has no binding force except for extensions to the existing building ¹³. Despite this, these texts will be used as a reference for local fire departments to issue a favourable or non-favourable opinion, even for retrofits.

Useful standards

- NBN \$ 01-400-1 Acoustic criteria for residential buildings
- NBN \$ 01-401 Acoustics: noise levels to avoid discomfort in buildings
- EN ISO 717-1 Acoustics:
 Rating of sound insulation in buildings and of building elements; Part 1:

 Airborne sound insulation
- EN ISO 717-2 Acoustics: Rating of sound insulation in buildings and of building elements; Part 2: Impact sound insulation
- EN 12354 Building acoustics. Estimation of acoustic performance in buildings from the performance of elements.

¹³ The prefabricated facade modules type TES can be used to extend the volume of the existing building, whether vertically by adding a storey or transformation of the last existing level, or horizontally by creating new spaces.



Three sizes of buildings are distinguished in the RD depending on the height h. The latter is defined as the distance between the finished level of the highest floor and the lowest level of roadways around the building which can be used by fire services. Depending on this height we have:

- Low buildings (h < 10 m)
- Medium buildings $(10 \le h \le 25 m)$
- High buildings (h > 25m)

(b) Fire resistance

The fire resistance of a component is the time expressed in minutes during which it satisfies one of several of the following **criteria**:

- Stability (R=Load-bearing): time during which the member retains its load-bearing function (for the bearing function elements).
- Sealing flame (E=Integrity): time during which there are no flames passing from at unexposed side
 of the wall (for items with a separating function).
- Thermal insulation (I=Insulation): time during which the temperature does not rise above a certain threshold temperature on the unexposed side.

An element must meet the functions that are assigned to it: load-bearing, separating, or bearing and separating.

At present in Belgium, the **fire resistance can be assessed by testing a specific configuration, by calculation or by analogy**. The standards are grouped in families depending on the type of test and the type of product, or their combination in some cases. The designer should always start from the General Requirements (EN 1363-1) and then the adequate test method for the component to be tested (**Figure 126**). The methods for determining the fire resistance by calculations are provided by the Eurocodes for different types of structure, in dedicated sections (e.g. *Eurocode 2: Design of concrete structures – Part 1-2: General rules – Structural fire design*).

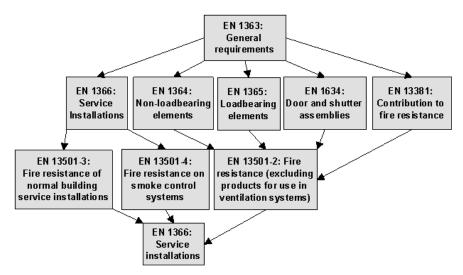


Figure 126. European standards for fire resistance. Source: BBRI



(c) Fire reaction

The 'reaction to fire' refers to a material and its **ability to feed the fire**. This is a particularly critical property for coating materials. Construction products are assigned with one of the 7 Euroclasses: A1, A2, B, C, D, E and F. The best materials in terms of reaction to fire are listed in the classes A and the worst in the class F. Two classes (A1 and A2) exist for the high level of exposure. A distinction is also made between classification of floor coverings and other materials. Additional classifications involve two complementary aspects to the contribution to fire. The first aspect relates to the generation of smoke ('s' for smoke). The second aspect relates to the production of droplets ('d' for droplets). Their indication is not required, unlike Euroclasses.

4.3.2 Attention points for AIMES modules

The Royal Decree does not apply to existing buildings, although the designer should try to improve the security situation as far as possible, if necessary by relying on specific investigations. When requesting building permits, local fire control services will issue an opinion (mandatory) as to the fire protection measures. To do this, the Royal Decree will serve as a decision guideline and new facade elements can under no circumstances worsen the existing fire-safety.

In the fifth book published within *smartTES* project [30], the following goals in terms of fire safety are specified for TES elements and can be applied to any AIMES system. These points are based on the principles from the document 'Essential Requirement N^2 – Safety in case of fire' from the European communities:

- Occupants shall be able to leave the building or be rescued
 - Keep the escape routes free
 - Limit the generation of smoke and its propagation
- The safety of rescue teams should be guaranteed
 - Limit the risk of large and heavy falling parts
 - Guarantee that extinguishing the fire in all part of the façade-system is possible
 - o Limit the generation of smoke and its propagation
- Load-bearing and separating structures and elements shall resist fire for the minimum required duration of time
 - Check this objective for the existing wall, but also for the AIMES element and its anchorage
- The generation and spread of fire and smoke on the façade should be limited, as well as the propagation inside de building and to neighbour buildings
 - o Plan structural fire-stops / extinguishing systems / low flammability materials
 - Plan fire-proof connection and joints
 - Prevent the 'chimney' effect: avoid cavities in the façade where flames and smoke can spread

In this framework, the AIMES design choices should be checked relatively to:

- The fire reaction of the chosen materials
- The fire resistance of the assemblies
- The assembly details (including attention on AIMES-incorporated building services and the adaptation layer)

The AIMES façade can be load-bearing or not load-bearing, with a separating function. The new facade covers the outside of the building and connects the apartments vertically. In case of fire, the propagation takes place vertically along the facade - from bottom to top. For this reason, it is essential that the course of fire is not favoured by the materials and the structure of the new façade assembly, or by the integrated systems.



Four different fire spread paths can be investigated to design a fire-safe assembly (Figure 127):

- 1. The separating function of the AIMES façade element itself and contribution to the fire resistance of the existing wall
- 2. Fire penetration into the AIMES element and a following uncontrolled propagation inside its structure. Two illustrative paths are indicated on the figure: from an indoor fire or from an external source.
- 3. Fire spread on the façade or behind a cladding system. Again, two possible paths of fire propagation are illustrated.
- 4. Fire spread at the junction AIMES element/existing wall, thus at the location of the adaptation layer. On the figure, the possibility of fire to penetrate at the location indicated with a star is critical and was not included in the original illustration. In any case, the resistance of the anchorage elements should be guaranteed.

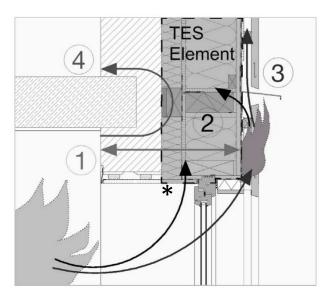


Figure 127. Fire scenario for planning a fire-safe assembly. Source: [30]

For medium and high buildings, the RD provides specific prescriptions for façades. To limit the risk of fire propagation vertically or horizontally between compartments along the façade, at least one of the following conditions must be met:

- i. The façade comes with a fire-resistant construction element at the junction between the façade and the floor/wall defining the compartment. The Figure 128 shows how such an element can be implemented for a compartment floor (to limit risks of vertical fire propagation between two storeys). The sum of dimensions a, b, c and d (in Figure 128) should equal at least 1m. A similar figure can be found in the RD for the horizontal fire propagation, with the associated prescriptions (see F.
- ii. Either the façade is characterized by E30 on its whole height or E60 on one storey out of every two
- iii. The compartments in contact with the façade are equipped with sprinklers (NBN EN 12845)

For the first solution (i) and with an appropriate material choice and conception, the AIMES solution can help the building to reach the RD criterion. However, it is crucial that no fire shortcuts exist, as for example through the adaptation layer as indicated on **Figure 127-(4)**. If the RD '1 meter' criterion was already respected on the existing building, all fire-shortcuts possibilities that can appear due to AIMES façade installation are still crucial to identify and resolved through an appropriate design.



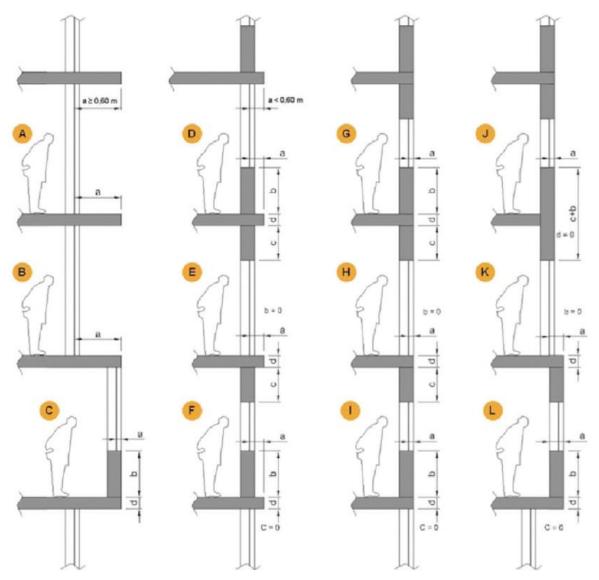


Figure 128. Various constructions and the computation of the resistant-meter (vertical propagation). Source: RD

The new facade system can be used to integrate ducts and cables. By doing so, old installations can be renewed without major work inside the building. However, it is essential to analyse the risks that rise from these new linear paths, which often alter the original compartmentalisation of the building (fire path shortcuts). The RD provides a series of prescriptions relative to this matter. Often, the designer will need to plan specific devices to meet these requirements (e.g. fire damper appended to a duct that goes through a wall for which an EI 60 resistance is required).

5. Construction phase

5.1 Chapter summary

This chapter describes the execution phases. Depending of the chosen level of prefabrication for industrialised modules, the involved **on- and off-site operations** can cover various degrees of complexity. Again, **an efficient communication between actors is essential.** The on-site installation of industrialised multifunctional envelope systems normally ensures reduced efforts due to the prefabrication in the factory. However, many interventions still need to be completed on-site. The following chapter provides an overview on these interventions, with some practical examples from the European cases.



How to organise the production and installation of the AIMES modules to guarantee an optimal final performance and limit the duration of the retrofit?

5.2 Off-site

5.2.1 Production planning

Here are the tasks linked to the planning of the modules production:

- Define the level of automation
- Choose the assembly lines
- Create and validate the production models
- Optimise the information transfer between the actors
 - Centralise information
 - Organise the workflow between the AIMES designer, producer(s) and subcontractors (data and products exchange)
- Properly configure the CNC machinery
- Optimise the flow/storage of materials and subassemblies
- Order raw materials
- Organise the storage and transport of modules ready to be assembled on-site

5.2.2 Prototyping

In order to presage potential problems during the on-site execution phase, 1:1 scale prototypes can be tested in workshop or directly installed on site. Modification in design can then be planned. In <u>Kapfenberg (AT)</u>, one module was mounted on the existing building to test the chosen design and the fixation system (**Figure 129**).

(5.2.1)

Relevant actor(s):

- Architect
- AIMES designer
- AIMES producer

Building contractor

Task(s)

 Plan the production of modules in a thoughtful way in order to minimise resource use and on-site adjustments

(5.2.2)

Relevant actor(s):

- Architect
- Building contractor
- AIMES designer
- AIMES producer

Task(s):

 If necessary, plan a prototyping phase that will allow to presage potential problems.



As described in [18], within the <u>Roosendaal (NL)</u> project a test phase was realised previous to the actual retrofitting plan. Two houses were retrofitted with an ETICS system and a third one with prefabricated envelope elements. During this test phase, the innovative technique could be studied in a technical point of view, leading to the elaboration of the final tender, and its inherent advantages could be highlighted.



Figure 129. Prototype module implemented in Kapfenberg (AT) before the actual execution

5.2.3 Production of modules

This phase starts with the elaboration of production drawings and models, based on the geometrical survey of the building. First, it is important to recall that various levels of information can be associated to the designation '3D model'. The lowest level of 3D information consists in visualization/communication data only. It is made off a group of points in space, with possible interconnections forming lines or faces, and associated with basic information (e.g. RGB). A good example of such level is the point cloud produced from the laser scan of one façade. In a further level, the 3D geometry is segmented into distinctive objects (e.g. walls, floor slabs, etc.). A modelling phase is necessary to extract geometric shapes from a raw model. It is rarely automated and requires time and skills. The great advantage of segmenting the model into real-world architectural objects is that it is then possible to assign some attributes to each one of them and generate a digital mock-up. It is the paradigm of a so-called 'intelligent modelling' or 'Building Information Modelling (BIM)'. The possible attributes assigned to a building component are numerous: type of material, LCA data, thermal properties, etc. In the next evolution, the model can reach a '4D' approach, when time or planning aspects are included. Many further levels can be achieved, as for example integrate costs evaluation and budget management, or automatically generate order forms.

(5.2.3)

Relevant actor(s):

- AIMES producer
- Land surveyor
- (Expert: Quality)

Task(s):

- Elaborate production plans
- Produce the modules up to the level of prefabrication determined during the design phase



Figure 130. Application of an airtightness tape around integrated ducts (<u>Augsburg</u>, <u>DE</u>)



It is easily understood that the benefits of a BIM approach are important when planning the production and mounting of AIMES. Within an object-oriented CAD software, a timber-based AIMES producer could typically:

- 1. Import the geometry of the existing building into the modelling environment. It possibly requires that the surveying model is processed (e.g. point cloud from a laser scan transformed into a mesh model)
- 2. Model the distribution of the AIMES modules around the existing building geometry
- 3. From point 2, generate the layout of all the timber frames of the AIMES modules
- 4. From point 3, determine all timber-timber, timber-concrete or timber-masonry connections types and associated connectors
- 5. From points 3 and 4, generate Computer AM data (i.e. instructions for cutting machines)
- 6. Generate a list of inputs: dimension and quantity of pre-cut framing material lists, fasteners, etc.

The steps 2, 3, 4, 5 and 6 can be highly automated in modern software solutions.

Once the production drawings have been validated, the production of modules can start (**Figure 131**). For structure-based designs, it includes the assembly of the structural frame and panels, with insulation if a closed system was retained. The integration of windows and systems should be well planned and the modalities adapted to the available machinery. The whole assembly process needs to be optimised and all possible problems should be foreseen. For timber-based AIMES modules, the entire process is based on 'traditional' methods of the timber frame construction industry with its quality control procedure.

The production phase of frame-based solutions covers the following tasks:

- Control of input materials
- Control of systems to be integrated (e.g. windows, ducts)
- Cut and mill the frames elements
- Assemble the frame
- Panel the frame on one side
- Integrate windows (optional)
- Assemble the integrated systems (optional)
- Incorporate the insulation layer (optional, can be blown on-site)
- Panel the frame on the other side (optional if open TES configuration)
- Incorporate the technical membrane(s) (optional)
- Incorporate joints and other airtightness elements (Figure 130)
- Incorporate elements of the external layer

The whole procedure is accompanied by:

- The inventory of and validation of deviations from production specifications
- The quality control procedure(s)

A particular attention must be paid to the protection of sensitive elements during transport.



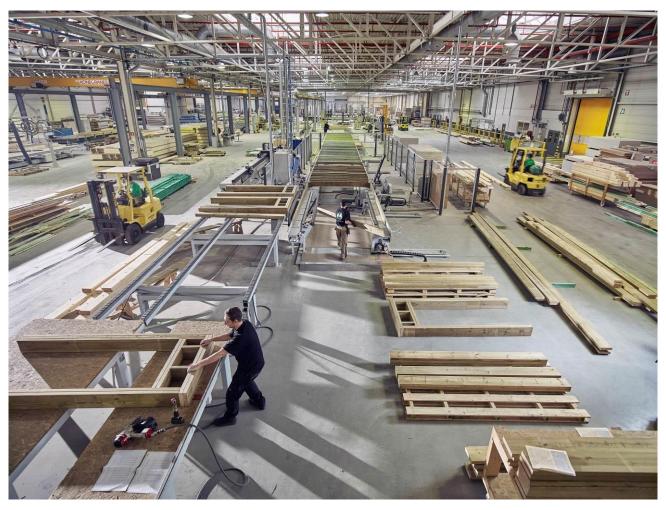


Figure 131. Off-site assembly of AIMES modules On-site. Source: Machiels Building Solutions

5.2.4 Planning of on-site interventions and coordination of efforts

The coordination of the involved actors is crucial. It covers the following tasks:

- Plan a clear sequence of intervention with all concerned actors (Figure 134). This sequence should be geared towards the limitation of the number of interventions from a same actor and the limitation of down time on-site. A very detailed LEAN planning is recommended.
- Optimise the information transfer
 - o Provide centralised communication media (e.g. plans, numerical models, register of interventions)
 - Organise the workflow between actors
- Optimise the available space with a proper site management that guarantees easy logistics of operations (Figure 135)
 - Plan space for storage
 - o Plan space for workers
 - Plan the use of cranes, with an analysis of operating ranges and proposals for settlement locations (Figure 132)
- Design scaffolding (if needed)
 - Dimensions
 - Distance from existing wall



- Rationalise the use of equipment (e.g. cranes) and infrastructures (e.g. scaffold) for the different teams
- Plan the logistic for deliveries, unloading and storage of materials, equipment and AIMES modules (see 5.2.8(b)).
- List all possible sources of hazard for occupants and workers and plan adequate measures to guarantee safety
- Plan a periodic on-site validation of the interventions
- Set up a clear communication with the occupants on planning and possible hindrances
- Set up and secure the construction site

Three main risks linked to on-site execution were identified during the E2Rebuild project [18]:

- The weather dependency
- The complexity: underestimation of detailing and lack of coordination at planning phase
- The conflict potential: multiple disturbance of occupants (e.g. blocking of access routes)

(5.2.4) Relevant actor(s):

- Architect
- AIMES designer
- Building contractor
- Expert: On-site communication
- Occupants
- Subcontractors

Task(s):

- Plan the intervention in a thoughtful way in order to:
 - minimise resource use
 - → optimise the intervention time
 - → limit the on-site adjustments
 - limit impact on occupants

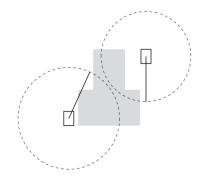


Figure 132. Operating range of cranes. Source [2]



Figure 133. Example of segmentation of operations (Roosendaal, NL)

On day 1, the outer leaf is removed; on day 2 the foundation is upgraded from the outside. On day 3, the concrete is left to harden whereas day four is reserved for disconnection of existing installations. The last day is exploited to remove the external layer of the existing cavity wall and the old roof deck and install the new modules for façade and roof.



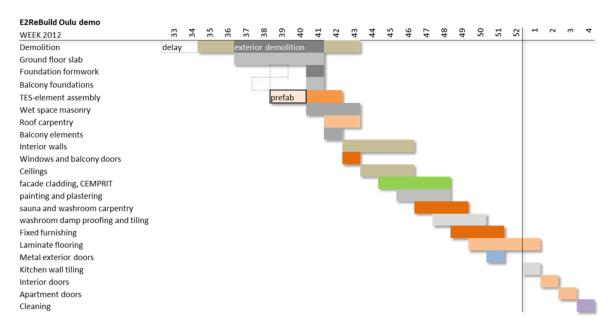


Figure 134. Example of how the on-site interventions were planned in Oulu, FIN. Source: [31]

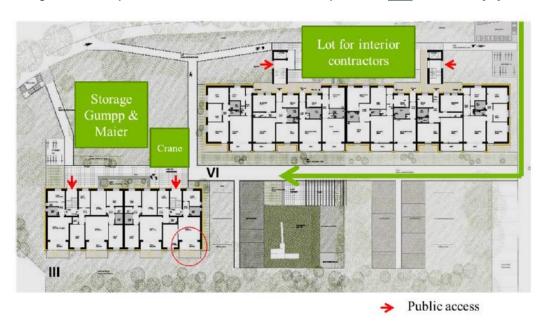


Figure 135. Site management planned in <u>Augsburg</u> (DE) project. Source: [32]

5.2.5 Practical dispositions relative to occupants during the intervention

The AIMES approach limits the nuisance for occupants by providing an accelerated on-site phase and by limiting the destructive operations. However, the project leader has to ensure that the satisfaction of occupants is kept to a good level. If heavy works are implied by the retrofit, the relocation of tenants can be

(5.2.5)

Relevant actor(s):

- Building operator
- Building contractor
- Expert: On-site communication
- Occupant
- Owner

Task(s):

 Take the necessary dispositions to ensure the lowest possible disturbance of occupants living conditions



considered (temporary or for the whole period). For interventions on the inside of the building (e.g. removal of old windows), or destructive operation on the external envelope, protective measures should be planned.

- If the relocation of occupants is foreseen
 - Organise the relocation (duration and modalities)
- If no relocation of occupants is foreseen¹⁴, plan the necessary dispositions to:
 - Guarantee a secure access to the building and individual apartments
 - Guarantee a limited impact on the usability of the building for occupants
 - Guarantee the safety of occupants
 - Limit the noise disturbance
 - Protect the indoor space (Error! Reference source not found.)



Figure 136. Dust screen installed to protect the indoor spaces during onsite interventions (Berlin)

 Make the existing building ready to receive the new façade modules by preparing and applying destructive

and upgrade interventions

(5.2.6)

Task(s):

Relevant actor(s):

See subtasks

5.2.6 Preparation of the existing building

(a) Destructive interventions

Here is a list of possible destructive interventions linked to the preparation of the existing building:

- Removal of wires of cables, electricity, street lighting, etc.
- Total removal of the existing outer wall (optional; not studied in this document)
- Partial removal of the existing outer wall (e.g. the external layer of the existing sandwich panel (Figure 137), the external layer of the existing cavity walls (Figure 138))
- Removal of external architectural elements such as chimneys, drain pipes, balconies, ... (Figure 139)
- Removal/levelling of small irregularities (size up to some millimetres) using renders or other.
- Removal of larger elements (centimetres) such as window or door sills, steps, larger decorations
- Removal of a soil layer to access to the foundation
- Removal of window elements or doors (if not possible after the mounting of AIMES façade)
- Adjustment of openings size
- Removal/disconnection of service systems (temporary or definitive) (Figure 140)
- ...

The removal of existing windows is a critical point. An early removal means that an adequate protection must be planned for tenants not to suffer from noise, outside temperature, dust, etc. The best is to keep the existing windows for a longest possible period, even after installation of the façade modules with new integrated

¹⁴ This is the preferable solution with AIMES solution



windows. However, in some cases the location of the existing windows will hinder to installation of AIMES modules. The architectural details of the windows construction can also prevent them from being removed from the inside.





Figure 139. Part of old balconies cut down in Augsburg, DE





Figure 140. Removal of old systems (Pettenbach, AT)

Figure 137. Partial removal of the existing sandwich walls (Riihimäki, FIN)



Figure 138. Partial removal of the existing cavity walls (<u>Roosendaal, NL</u>)

(b) Interventions against pathologies

It is essential that all existing pathologies (identified during the investigation phase – see **2.3.1(a)**) are treated to ensure a durable retrofit. Those may include: moisture-related damage, defects in the lintel construction, cracks in the façade or structural elements, corrosion of metallic elements (e.g. anchorages of a cavity wall), etc. The installation of façade modules can worsen existing

(5.2.6(b)) Relevant actor(s):

- Building contractor
- Experts: Pathologies remediationTask(s):
 - Make the building healthy before mounting the new façade modules and technologies
 - Confirm that no new pathology could appear

problems or create new ones; that explains why a deep investigation phase is needed, including a study related to the hygrothermal behaviour of the building and the impact of new superimposed layers on this behaviour. Moreover, many interventions should be preferentially performed before the mounting of modules as the latter can limit the accessibility for treatment procedures. It is important to note that interventions against humidity problems in the mass of existing walls often require a sufficient drying time; the presence of façade modules can also greatly increase this necessary period. The condition of structural elements is another critical aspect, and solutions should be provided to guarantee the structural safety and limit issues for modules anchorage.

An adequate control of the quality of interventions should also be planned with specific experts.



(c) Upgrading interventions

Structure and envelope

Here are some possible interventions linked to the upgrading of structure and envelope:

- Pre-filling of cavity walls in case the outer leaf is not being removed
- Fixation of the existing outer leaf in a situation where the existing brick wall ties are corroded or subjected to corrosion within the new lifespan
- Reinforcement of the load-bearing structure
- Mounting of a temporary or definitive levelling substructure (Figure 141)
- Mounting of a levelling compression layer
- New load-bearing elements (brackets, additional foundation (Figure 142), footings, etc.)
- Preparation for the module anchorage
- ...

Indoor spaces and service systems

List of some possible interventions:

- Drill holes for the new ventilation systems (Figure 143)
- Feed electrical wires to the required locations
- Install protective layers for the indoor spaces
- Adapt the indoor spaces to maintain access for the occupants
- Fix cables or small ducts in an installation zone on the existing walls
- .



Figure 143. Holes drilled in the existing walls to connect the ventilation ducts (Riihimäki, FIN)

(5.2.6(c))

Relevant actor(s):

- Building contractor
- Subcontractors: HVAC / Structure ...Task(s):
 - Prepare the building for AIMES façade by upgrading the required components



Figure 141. Fixation of an alignment beam in <u>Berlin</u>, <u>DE</u>







Figure 142. Implementation of new foundation in Roosendaal, NL



5.2.7 Practical dispositions relative to moisture protection during the assembly phase

Some materials in the prefabricated envelope elements might be **vulnerable to moisture during the assembly phase**, which can be a real challenge. Temporary weather protection measures should be provided for critical elements (**Figure 144**). Here are some attention points mentioned in the fourth book published within the smartTES project [28]:

- The protection of modules with a high degree of completion can be more critical during the transport, storage and assembly phases because drying conditions are worse than for modules without insulation and/or vapour barrier. A quick on-site assembly is thus preferable for highly prefabricated AIMES systems.
- Generally, because the top façade elements are more subject to moisture intrusion, adequate rain protection should be planned on their top if an exposure risk exists. This is especially important if the assembly of the new façade modules starts on the lower storey.
- The mounting of the wooden sill (if it is used in the design) is also particularly critical, especially if the weather exposure is expected to be long before the installation of the AIMES modules.

(5.2.7)

Relevant actor(s):

- Building contractor
- Module producer

Task(s):

 Guarantee that the new envelope elements are protected against the rain and any other possible water damage



Figure 144. Protection of installed modules before the implementation of the cladding (<u>Oulu, FIN</u>)

5.2.8 Mounting of façade modules

(a) Preconditions

As mentioned in [18], the process of AIMES mounting can start once the following preconditions are checked:

- The production is completed
- The coordination of workforce during the assembly is planned
- The schedule for the site interventions is validated
- The assembly plans are ready
- Site and building access: the transportation and assembly are possible
- The site infrastructure is ready (e.g. cranes)
- The temporary attachment points on the façade modules are defined (e.g. crane attachment points, handles for manual alignment)
- The impact analysis of each activity on-site is checked with health and safety instructions
- The fixation points are defined
- The existing structure is checked for its load-bearing capacity and the risks of anchorage failure
- The dismantling of façades, balconies and foundations is finished
- The required upgrading interventions are finished

(5.2.8)

Relevant actor(s):

- Building contractor
- (AIMES designer)

Task(s)

- Deliver and store the façade modules
- Mount and anchor the modules according to the AIMES designer prescriptions
- Ensure that façade modules are properly protected during the assembly phase



The risk management and the responsibilities of actors are defined

(b) Transport and storage

The transport of AIMES elements from the factory to the building site should be well-planned with considerations regarding the AIMES modules production rates, the phasing of façade installation, and the storage capacities. The decision includes:

- The transport modalities from production lines to the storage site in the factory
- The transport modalities from the storage site in the factory to the building site:
 - Frequency of delivery regarding the mounting phasing and the on-site storage capacity
 - Type of truck used for transport (see below)
 - Loading and unloading equipment
 - Number of trucks for one delivery
 - 0

A meticulous study of the transportation route and potential obstacles is crucial when dealing with large AIMES façade elements. Normally, those were conceived with regard to accessibility limitations but all the risks of having the delivery convoy blocked at the time of construction should be analysed in advance (including temporary obstacles that may not have been identified during the preliminary studies).

General regulations for transport within EU, as presented in the Directive 96/53/EC, define the maximum dimensions and weight for transportation trucks (Table 40, Table 41). This information has to be integrated into the design process to limit the size and weight of AIMES elements in consideration of the characteristics of existing routes from the factory to the destination building. The reader should note that a 'Modular Concept' (EMS - European Modular System) was also introduced in 96/53/EC that allows to increase the vehicle length and weight on appointed road networks on the condition that 'standard' road-train configurations are used 15 (Figure 145). If applied in Belgium in the future, the longest (and heaviest) trucks configurations should be considered only for long-distance transport, and never for final delivery in an urban context.

Table 40. Maximum dimensions allowed for transportation trucks.

Height	Width	Length			
		Lorry or trailer	Road train	Articulated vehicle	
4m	2.55m	12m	18.75m	16.50m	

Table 41. Maximum weight allowed for transportation trucks.

Weight pe bearing axle	Weight drive axle	per	Lorry 2 axles	Lorry 3 axles	Road axles	train	4	Road axles	train and +	5	Articulated vehicle 5 axles and +
10t	12t		19†	26t	39t			44†			44†

¹⁵ Not applicable in Belgium for the moment



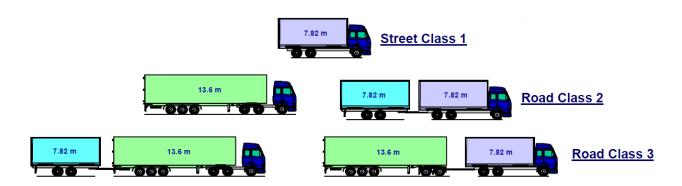


Figure 145. Examples of 'mega truck' combinations based on EMS that might be allowed in the future. Source: [33]

In Roosendaal, AIMES modules were produced 250km away from the site. All prefabricated elements for retrofitting one house (among 134 in total) were transported on one truck which travelled during the night for installation the next day.



Figure 146. Charging the modules for on-site delivery (Roosendaal, NL)

(c) Lifting and fixation

The installation of modules in front of their final mounting location requires some manipulation with mobile or standing cranes (Figure 147). Temporary attachment points on AIMES elements for lifting and manipulation are required (Figure 148). In Berlin (DE) temporary wood beams were fixed to the modules for which the crane accessibility was difficult (Figure 148). Handles should also be provided for manipulation by workers (e.g. façade modules alignment). Such necessary adjustments should be planned well in advance. The lifting equipment must be adapted to the weight of the heaviest element, to the dimensions of the largest element, and to the highest location to reach. We recall that if modules are planned to be installed vertically, a tilting operation is necessary (Figure 149). AIMES always needs to be designed to withstand load implied during transportation and mounting.

For modules with a high degree of prefabrication, the mounting phase can be really quick. For <u>Graz-1</u> project, one 4-storey façade was assembled within half a day (**Figure 151**).





Figure 147. Overview of the mounting equipment in Berlin (DE)

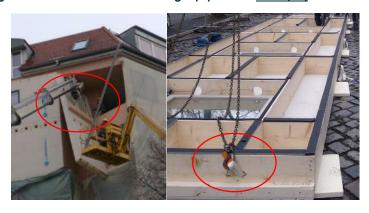


Figure 148. Use of a temporary attachment point to cope with crane accessibility or to provide lifting points (Berlin, DE)



Figure 149. Tilting of modules in Riihimäki (FIN)





Figure 150. Fixation of the module to the attachment substructure: <u>Augsburg</u> (<u>DE</u>) and <u>London (UK)</u> cases show a similar fixation method



Figure 151. Assembling procedure in Graz-1. Source: [21]



5.2.9 Additional/finishing works

The level of additional/finishing works depends on the AIMES prefabrication level. Depending on the design choices, possible interventions include:

- Remove existing windows from the inside
- Inject loose-fill insulation (main insulation or adaptation layer) (Figure 152)
- Install junctions elements
 - Module-module, module-roof, roof-roof
 - Movement and air tightness joints
- Install exterior membranes, cladding and finishes (Figure 153)
- Install exterior systems (solar systems, balconies, overhangs, ...) (Figure 154, Figure 155)
- Install corner protections
- Install decentralised ventilation units
- Indoor finishing works (Figure 156)
- Cleaning operations



Figure 154. Additional architectural elements fixed on modules (<u>Riihimäki, FIN</u>)



Figure 155. Installation of PV panels in Pettenbach (AT)

(5.2.9)

Relevant actor(s):

- Building contractor
- Subcontractor (e.g. solar panels)
- (Expert: Quality)

Task(s):

 Perform all the operations required to complete the retrofitting





Figure 152. Insulation injection for Open TES modules (top) <u>Pettenbach, AT</u> (bottom) <u>Berlin, DE</u>





Figure 153. On-site fixation of external layer (top) Trespa panel in Berlin





Figure 156. Installation of airtightness tape in Pettenbach (AT)

6. Post-construction phase

6.1 Chapter summary

This last chapter describes the stages that follow the retrofitting operations and that consist in (1) controlling that these operations were implemented correctly, (2) ensuring that the building performs or will perform as planned, in parallel (3) bring the necessary preventive and corrective actions, and (4) plan the maintenance of systems. From the beginning of the project, the owner and the project team should have these post-constructive actions in mind.



How to ensure that the building retrofitted with AIMES performs as planned?

6.2 Project commissioning

It is important that **key final quality and performance targets** linked to durability, energy use and indoor environment are acknowledged by the different actors of the project before the construction phase. These requirements should be partly **translated into measurable quantities** (presence of pollutants in the air, surface temperature, U-levels, air infiltration rates, etc.) which can be **controlled by designated teams** after the construction. Of course, the quality control is a whole-project procedure, and the final check of the system is just a part of it.

Actions within the commissioning should include the verification of specific AIMES implementation prescriptions (from the AIMES designer and producer) by using a list of critical points to ascertain (air tightness, moisture protection, modules alignment).

The investigation methods include:

- Visual inspection
- Photogrammetry studies
- Blower door test
- Thermography
- Measure of the moisture content in specific locations
- o ..

For open AIMES solutions, it is particularly relevant to inspect the conformity of the insulation blowing. An improper uniformity of the insulation layer, due to a differential settling, will clearly appear on thermographic inspections.

(6.2)

Relevant actor(s):

- Architect
- AIMES designer
- AIMES producer
- Experts: Building Physics / Diagnostics / EPBD / Quality
- Owner

Task(s):

 Assess the conformity of module implementation with regards to the design process

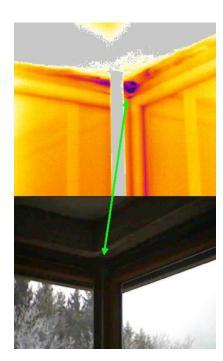


Figure 157. Thermal imagery survey in <u>Pettenbach</u>. Problems linked to the installation of the wind-proof tape were higlighted (resulting in a thermal bridge)



6.3 Monitoring

The term 'monitoring' covers all the **methods that allow to evaluate the performance of the building over a certain period of time using the measurement of a certain physical quantity**. A monitoring phase is very useful to assess the quality of the retrofit, verify the energy performance, and identify possible problems that could not be highlight with direct assessment methods.

In its simplest form, the monitoring phase may consist in surveying the energy consumption of the building (for heating and/or DHW).

(6.3) Relevant actor(s):

- Building operator
- Experts: Building Physics / HVAC & building services / EPBD / Diagnostics
- Universities or research centers

Task(s):

 Check the quality of the retrofitting process with an adequate monitoring phase

In contrast, complex approaches are characterised by the implementation of various types of sensors, not only in rooms but also inside envelope elements. A specific user interface could also be implemented, to broaden the accessibility to data (Figure 158). Such developments open the perspective towards 'smart' control of the indoor environment.

The data collected from measurement campaigns can be used to validate computational models. In fact, many research centres or universities will seek to get such validation material and collaborations can be found so that both their teams and the owner get benefits from the monitoring phase. When trying to analyse the monitored datasets from an occupied building, it is always crucial to keep in mind that occupants can have a strong impact on the measured quantities, because of their activities and their interaction with controllable equipment (e.g. opening windows, changing thermostat values).



Figure 158. Screenshots from an online interface implemented in Oulu for accessing monitoring data. Source: [31]



Table 42 shows some typical variables that can be monitored to assess the energy performance and the indoor comfort of the retrofitted building, calibrate and validate models, or adjust the building services.

Table 42. Some energy related and hygrothermal variables that can be monitored after completion of an AIMES retrofit

Monitored quantity	Usage
Purchased energy	Energy efficiency assessment / Models validation
Space heating energy consumption	Energy efficiency assessment / Models validation
DHW energy consumption	Energy efficiency assessment / Models validation
Electricity consumption	Energy efficiency assessment / Models validation
U value	Energy efficiency assessment / Models input
Indoor temperature	Comfort assessment / Systems adjustments
Indoor humidity	Comfort assessment / Systems adjustments
Indoor air velocity	Comfort assessment / Systems adjustments
Ventilation rates	Comfort assessment / Energy efficiency
V G T T T G T G T G T G T G T G T G T G	assessment / Models input / Systems adjustments
Outdoor temperature	Models input / Energy efficiency assessment
Outdoor humidity	Models input
Outdoor wind (speed, direction)	Models input
Sunlight	Models input

<u>Oulu (FIN)</u> and <u>Roosendaal (NL)</u> retrofits, both case studies of E2Rebuild research project, were followed by intensive monitoring campaigns.

6.4 Preventive and corrective actions

One first category of actions that directly follow the retrofit operations are **preventive**: they allow to ensure that the occupants have the necessary knowledge concerning the modifications of the building. If occupants do not understand how the changes in the building may be beneficial to them, especially if there is an increase of the rent, they might express dissatisfaction. Moreover, **a bad understanding of the new systems (e.g. how they work, what is the user control level, how**

(6.4)

Relevant actor(s):

- Architect
- AIMES designer
- Building operator
- Expert: communication
- Occupants
- Owners

Task(s):

 Guarantee the good use of the building and bring necessary modifications

the indoor environment should be) can lead to discrepancies between planned and actual performance. For all these reasons, ways of communicating with occupants should be planned after the retrofitting operations. It can takes various form depending on the expressed needs or the observed issues: meeting, manuals, posters, etc. Ideally, this should not be a one way communication; real interaction should be sought for. Examples in European project implementation have shown the benefits of organising regular meetings with occupants or their representative. In a simpler form, survey can be implemented easily. A particular attention should be paid to the communication medium (e.g. language barrier, simplicity of information)

If preventive actions failed and/or the planned performance is not guaranteed, there is a need for **corrective** actions. These may include:

- Direct intervention on the envelope to fix a defect or improve some details
- Direct intervention on the operation strategy of building services
- Changes in the way building services are controlled (e.g. implement an intelligent control)

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Annex: case studies

This section presents the case studies used all along this document. It includes cross sections of the prefabricated modules used for each case, with information concerning:

- The thickness of the various layers
- Their role and type
- The type of assembly (on-site or off-site).

Wood-based board or cladding	Mineral-based board, cladding or plaster	Air gap	Light material	Technical layer

Figure 159. Colour map used to identify the type of construction materials

ON	Material layer implemented on-site
OFF	Material layer implemented off-site (in the workshop)

Figure 160. Colour map used to identify how a particular layer of the AIMES module is implemented

List of cases

- Augsburg (DE)
- Berlin (DE)
- Buchloe (DE)
- Graz 1 (AT)
- Graz 2 (AT)
- Kapfenberg (AT)
- London (UK)
- Oulu (FIN)
- Pettenbach (AT)
- Riihimäki (FIN)
- Roosendaal (NL)
- Zürich (CH)

AUGSBURG (DE)

*=No information

General ir	formation			
Address Grüntenstraße, Augsbur				
Associated project(s)	E2Rebuild			
' ' ' ' '	TES			
Date of construction		66		
Type of building		Large apartment block (6-storey)		
Existing walls	Massive (bri			
Façade area [m²]		00		
Retrofit	i			
Advanced geometrical survey		otogrammetry		
Volume extension	Integration of existing balconies of winter garden (+182 m²) New balconies in the plane of the older ones			
Floor area before/after [m²]	*	*		
U of exterior walls before/after [W/(m²K)]	1.6	0.12		
Space heat demand before/after [kWh/(m²y)]	145	33		
Occupied during refurbishment	N	lo		
Time for façade installation	8 we	eeks		
Mounting equipment		olding crane		
Façade	modules			
Туре	Close	ed TES		
Orientation	Horiz	ontal		
Typical dimensions		0x2.8m)		
Typical weight	3 tons for	1 module		
Type of adaptation layer	Substructure (H) + 60mm blown cellulose			
Anchorage configuration	Standing configuration Articulated single-storey span			
Load transfer at building base	New foundation			
Building equipment & services	New windows (triple glazing, Uw=0.98) Blinds behind cladding			
Module	section	.a c.addii ig		

			Exterior air				
ON	28mm	Vert. wood cladding	140/28 spruce boards				
ON	30mm	Air gap + battens	30/50mm wood battens				
ON		Wind and rain-screen					
OFF	15mm	Front panel	Gypsum board				
OFF	200mm	Structure	60/200 KVH				
OFF	20011111	Insulation	Blown Cellulose				
OFF	10mm	Back panel	OSB				
ON	60mm	Adaptation layer	Blown Cellulose + substructure				
	Existing wall						



After



Off-site



On-site



BERLIN (DE)

*=No information

General information					
Address	BurgmeisterStrasse, Berlin				
Associated project(s)		-			
Date of construction	1960's				
Type of building	Large apartmen	t block (7-storey)			
Existing walls	Mas	ssive			
Façade area [m²]	,	*			
Retrofit	project				
Advanced geometrical survey	N	0			
Volume extension	Balconies i	integration			
Floor area before/after [m²]	*	*			
U of exterior walls before/after [W/(m²K)]	*	0.15			
Space heat demand before/after [kWh/m²y)]	*	<15			
Occupied during refurbishment	No				
Mounting equipment	Lift platform Mobile crane				
Façade	modules				
Type	Ope	n TES			
Orientation	Ver	tical			
Typical dimensions	Large (largest d	imension = 12m)			
Type of adaptation layer	Blown-in insulation	n (main insulation)			
Anchorage configuration	Distributed configuration Multi-storey span				
Building equipment & services	New windows (quadruple glazing, Uw=0.65) Sun blinds in windows Ducts + cables (network & electricity) in air gap behind cladding				
Module	section				

		Exterior ai	r		
ON	10mm	Panelling	HPL panels		
ON	80mm	Air gap	+ battens		
ON		Wind and	rain-screen		
OFF	15mm	Front panel	Gypsum board		
OFF		Structure	Timber studs		
ON	28mm	Insulation	Blown Cellulose		
ON	40mm	Adaption layer			
Friction visit					
		Existing wa			



After



Off-site



On-site





BUCHLOE (DE)

*=No information

General ir	nformation		
Address Kerschensteinerstraße, Buchle			
Associated project(s-	TES		
Date of construction	19	80	
Type of building	School (3-storey)		
Existing walls	Concrete	e parapet	
Façade area [m²]	48	600	
Retrofit	project		
Advanced geometrical survey		*	
Volume extension	N	lo	
Floor area before/after [m²]	8903	8903	
U of exterior walls before/after [W/(m²K)]	1.34	0.1	
Space heat demand before/after [kWh/(m²y)]	89.9 16		
Occupied during refurbishment	No		
Mounting equipment	Crane Scaffolding		
Façade	modules		
Туре	Close	ed TES	
Orientation	Horiz	ontal	
Typical dimensions	Large (8	i.8x3.5m)	
Typical weight		d module (about of façade)	
Type of adaptation layer	Compres	sion layer	
Anchorage configuration	Standing configuration Single-storey span		
Load transfer at building base	L-profile		
Building equipment & services	New windows (triple glazing) Blinds (in the plane of cladding)		
Module	section		

			Exterior air				
ON	24mm	Hor. wood cladding	Larch boards				
OFF	24mm	Air gap + battens	40/24mm wood battens				
OFF			Wind and rain-screen				
OFF	12.5mm	Front panel	Gypsum board				
OFF	100mm	Hor. structure	60/100 timber				
OFF	10011111	Insulation	Mineral wool				
OFF	200mm	Vert. structure	80/200 Glued laminated timber				
OFF		Insulation	Mineral wool				
OFF	15mm	Back panel	OSB				
ON	35mm	Adaptation layer	Mineral wool				
	Existing wall						



After



Off-site



On-site



GRAZ-1 (AT)

*=No information

General ir	nformation			
Address	Dieselwe	g, Graz		
Associated project(s)	Annex 50 SQUARE			
Date of construction	195	59		
Type of building	Large apartment	block (4-storey)		
Existing walls	Mass	sive		
Retrofit	project			
Advanced geometrical survey	*			
Volume extension	Balconies ir	ntegration		
Floor area before/after [m²]	1091	1589		
U of exterior walls before/after [W/(m²K)]	*	~0.18		
Space heat demand before/after [kWh/(m²y)]	184	9.6		
Occupied during refurbishment	No			
Mounting equipment	Lift platform Mobile crane			
Façade	modules			
Туре	Closed	d TES		
Orientation	Horizo	ontal		
Typical dimensions	Larç			
Type of adaptation layer	Levelling laths + wo			
Anchorage configuration	Standing com Articulated sing	'		
Load transfer at building base	L-profile			
Building equipment & services	New windows TES-integrated (decentralised ventilation units with heat recovery) TES-concepts (passive solar façade panes)			
Module section				

	Exterior air				
OFF	6mm		Security glass		
OFF	29mm		Air gap		
OFF	30mm	Solar comb	Alveolar carton board		
	19mm	Front panel 1	DFP fibreboard		
	16mm	Front panel 2	OSB		
OFF	120mm	Structure	Timber studs		
OFF	12011111	Insulation	Mineral wool		
OFF	19mm	Back panel	OSB		
ON	60mm	Adaptation layer	Mineral wool + substructure		
	Existing wall				



After



On-site



GRAZ-2 (AT)

*=No information

General information				
Address	Liebenauer Hauptstrasse, Graz			
Associated project(s)		-		
Date of construction	19	79		
Type of building	High rise apartme	nt block (7-storey)		
Existing walls		ed bricks 300mm)		
Façade area [m²]	98			
Retrofit	project			
Advanced geometrical survey		*		
Volume extension	Balconies in	corporation		
Floor area before/after [m²]	2616	*		
U of exterior walls before/after [W/(m²K)]	*	~0.18		
Space heat demand before/after [kWh/(m²y)]	135	8		
Occupied during refurbishment	:	*		
Mounting equipment	Lift platform Mobile cranes			
Façade	modules			
Туре	Close	ed TES		
Orientation	Horiz	ontal		
Typical dimensions	Large			
Type of adaptation layer	Levelling laths + 100mm mineral wool			
Anchorage configuration	Standing configuration			
Load transfer at building base		ofile		
Building equipment & services	ventilation units with heat recover TES-concepts (passive solar faço panes & PV for domestic hot wa			
Module section				

	Exterior air					
OFF	6mm		Security glass			
OFF	29mm		Air gap			
OFF	30mm	Solar comb	Alveolar carton board			
	19mm	Front panel 1	DFP fibreboard			
	16mm	Front panel 2	OSB			
OFF	120mm	Structure	Timber studs			
OFF	12011111	Insulation	Mineral wool			
OFF	19mm	Back panel	OSB			
ON	60mm	Adaptation laver	Mineral wool + substructure			
Existing wall						



After



On-site



KAPFENBERG (AT)

*=No information

General information				
Address	Johann-Böhm-Straße, Kapfenberg,			
1.12.2.2.2	Austria			
Associated project(s)	Haus der Zu			
Date of construction	1960	* .		
Type of building	Large apartment l attic			
Existing walls	Prefabricated san	idwich elements		
Façade area [m²]	162	22		
Retrofit	project			
Advanced geometrical survey	*			
Volume extension	Removal of ol New bal			
Floor area before/after [m² - heated area]	2756	*		
U of exterior walls before/after [W/m²K)]	0.87	0.17		
Space heat demand before/after [kWh/m²y)]	er * 15			
Occupied during refurbishment	Ye	S		
Mounting equipment	*			
Façade	modules			
Туре	Open TES with back membrane (hybrid)			
Orientation	Vertical			
Typical dimensions	Larg	ge		
Type of adaptation layer	Substru	cture		
Anchorage configuration	Standing configuration Multi-storey span			
Load transfer at building base	New foundation			
Building equipment & services	New windows (triple glazing, Uw=0.9) TES-concepts (PV panels & Passive solar facade panels)			
Module		, ,		

		Exterior air		
OFF	24	Panelling	Fibre cement panels	
OFF	50	Air gap + battens		
OFF	59	Front panel	Medium dense fibre board	
OFF		Structure	KVH	
OFF	200	Insulation	Blown mineral wool +	
OFF	105	Adaption layer	substructure	
- Vapour barrier				



After



Off-site





On-site



LONDON (UK)

*=No information

General information				
Address	Parkview hub, Thamesmead,			
	London			
Associated project(s)	E2Rebuild			
Date of construction		960's		
Type of building		ouses (5-storey)		
Existing walls		ited concrete		
	(insula	tion=5cm)		
Façade area [m²]		*		
Retrofit	project			
Advanced geometrical survey				
		incorporation		
Volume extension		w attic		
		erior corridor		
Floor area before/after	New	terraces		
[m²]	*	*		
U of exterior walls before/after [W/(m²K)]	1.67	0.12		
Space heat demand before/after [kWh/(m²y)]	186	<20		
Occupied during refurbishment		Yes		
Mounting equipment	Crane Scaffolding			
Façade i				
Туре	Closed TES			
Orientation	Horizontal			
Typical dimensions	L	arge		
Type of adaptation layer	Substructure (H) + compression			
Type of adaptation layer	layer (60mm mineral wool)			
Anchorage configuration	Standing configuration			
Anchorage Configuration	Articulated single-storey span			
Load transfer at building base		crete on L-Profile		
		windows		
Building equipment & services Ventilation: Intake/exhaust ou pre-fitted in factory				
Module section				

	Exterior air				
OFF		Vert. wood cladding	Coated spruce boards		
OFF	30mm	Air gap + battens	30/50mm wood battens		
OFF			Wind and rain-screen		
OFF	15mm	Front panel	Gypsum board		
OFF	280mm	Structure	60/280 timber studs		
OFF	200111111	Insulation	Blown Cellulose		
OFF	15mm	Back panel	OSB		
ON	68mm	Adaptation layer	Blown Cellulose + substructure		
	Existing wall				



After



On-site



OULU (FIN)

*=No information

General information				
Address	Virkakatu, Oulu, Finland			
Associated project(s) E2Rebuild TES				
Date of construction	198	34		
Type of building	Small apartment	block (2-storey)		
Existing walls	Prefabricated sar			
Façade area [m²]	48	0		
Retrofit	project			
Advanced geometrical survey	*			
Volume extension	New ba Roof overhar			
Floor area before/after [m²]	*	*		
U of exterior walls before/after [W/(m²K)]	0.28	0.12		
Space heat demand before/after [kWh/(m²y)]	148	26		
Occupied during refurbishment	No)		
Mounting equipment	Lift platform Mobile crane			
Façade ı	modules			
Туре	Closed TES			
Orientation	Horizo	ontal		
Typical dimensions	Large (~1	0x3.5m)		
Type of adaptation layer	Compression layer (50mm mineral wool)			
Anchorage configuration	Anchorage configuration Anchorage configuration Articulated singe-storey spo			
Load transfer at building base	New four	ndation		
Building equipment & services				
Module	section			

	Exterior air				
ON	7mm	Vert. mineral cladding	Corrugated fibre cement board		
OFF	44mm	Air gap + battens	2x22/100mm wood battens		
OFF	9mm	Front panel	Gypsum board		
OFF	48mm	Structure horizontal	42/48mm timber studs		
OFF	4011111	Insulation	Mineral wool		
OFF	198mm	Structure vertical	42/198mm timber studs		
OFF	17011111	Insulation	Mineral wool		
OFF	9mm	Back panel	Spruce plywood		
ON	50mm	Adaptation layer	Mineral wool		



After



Off-site





On-site



PETTENBACH (AT)

*=No information

General information			
Address Pettenbach			
Associated project(s)			
Date of construction	196		
Type of building	Single family ha		
Existing walls	Wood chip		
Façade area [m²]	*******	CONCIENC	
	project		
Advanced geometrical survey	project		
Advanced geometrical solvey	Extra s	torov	
Volume extension	Horizontal	,	
Floor area before/after [m²]	97	217	
U of exterior walls before/after [W/(m²K)]	1.0	0.11	
Space heat demand before/after [kWh/(m²y)]	ore/after 280 1		
Occupied during refurbishment	N	•	
Mounting equipment	Mobile	crane	
Façade	modules		
Туре	Oper	n TES	
Orientation	Horizo	ontal	
Typical dimensions	Lar	ge	
Type of adaptation layer	Blown-in insulation	(main insulation)	
Anchorage configuration	Distributed configuration Singe-storey span		
Building equipment & services	Building equipment & services New windows (triple glazing) Solar blinds TES-concepts (PV panels on faço modules)		
Module section			

		Exterior air	
OFF	30mm	Hor. Wood Cladding	Wood boards
OFF	45mm	Air gap -	+ battens
OFF	16mm	Front panel	Medium dense fibre board
OFF		Structure	Timber studs
ON	355mm	Insulation	Discos Callabase
ON	ŝ	Adaption layer	Blown Cellulose
		Existing wa	I



After



On-site





RIIHIMÄKI (FIN)

*=No information

General information				
Address	Saturnuksenkatu, Riihimäki, Finland			
Associated project(s)	TES Innova (FIN)			
Date of construction	19	975		
Type of building	Large apartmer	nt block (4-storey)		
Existing walls	Prefabricated so	andwich elements		
Façade area [m²]		*		
Retrofit p	roject			
Advanced geometrical survey	Laser s	canning		
Volume extension		es (steel frame) I spaces on roof		
Floor area before/after [m²]	*	*		
U of exterior walls before/after [W/(m²K)]	0.25	0.1		
Space heat demand before/after [kWh/(m²y)]	978			
Occupied during refurbishment	Y	'es		
Mounting equipment	Cr	ane		
Façade m	odules			
Туре	Clos	ed TES		
Orientation	Vei	rtical		
Typical dimensions	Large (largest	dimension=12m)		
Type of adaptation layer	Substructure (H) + 70mm mineral wool			
Anchorage configuration	Standing configuration Multi-storey span			
Load transfer at building base		isting foundation		
New windows (quadruple glazi Uw=0.66) Building equipment & services TES-connected (ventilation du from centralised system inside modules)				
Module section				

Exterior air					
ON	10mm	Render			
OFF	50mm	Insulation board, Plaster base	Mineral wool		
OFF	Ś	Front panel	Fibre cement		
OFF	300mm	Structure	39/300 LVL		
OFF	30011111	Insulation	Mineral wool		
OFF	9mm	Back panel	Spruce plywood		
ON	70mm	Adaptation layer	Mineral wool + substructure		
Existing wall (external layer removed)					



After



Off-site





On-site



ROOSENDAAL (NL)

*=No information

General info	ormation			
Address	Roosendaal, Th	ne Netherlands		
Associated project(s)	IEA Annex 50 E2Rebuild			
Date of construction	195	8-66		
Type of building	Terraced houses (2 stories + attic)			
Existing walls	Cavity wall			
Façade area [m²]	*			
Retrofit p	roject			
Advanced geometrical survey	No			
Volume extension	No			
Floor area before/after refurbishment [m² - heated floor area per house]	120	120		
U of exterior walls before/after [W/(m²K)]	0.8	0.09		
Space heat demand before/after [kWh/(m²y)]	95	22		
Occupied during refurbishment	Yes			
Time for façade installation	5 day per house			
Mounting equipment	Mobile crane Scaffolding			
Façade m	iodules			
Туре	Closed TES			
Orientation	Vertical			
Typical dimensions	Medium (largest dimension=~6m)			
Type of adaptation layer	Cavity sealed around window frames			
Anchorage configuration	Standing configuration Multi-storey span			
Load transfer at building base	Extension of existing foundation			
Building equipment & services	New windows (triple-glazed)			
Module section				

		Exterior air		
ON	Ś	Mineral cladding	Natural slates	
ON	+- 20mm	Air gap + hor. battens	Wood battens	
OFF	+- 20mm	Air gap + vert. battens	Wood battens	
OFF	16mm	Front panel	Wood fibre board	
OFF	350mm	Structure	I-Beam	
OFF	33011111	Insulation	Blown cellulose	
OFF	15mm	Back panel	OSB	
Existing wall (external layer removed)				



After



Off-site



On-site



ZÜRICH (CH)

*=No information

General information				
Address	Address Segantinistrasse, Zürich, Switzerland			
Associated project(s)	IEA Task 37 IEA Annex 50			
Date of construction	1954			
Type of building	Small apartment block (3 stories + attic)			
Existing walls	Massive (bricks 320mm)			
Façade area [m²]	*			
Retrofit	project			
Advanced geometrical survey	Laser scanning			
Volume extension	Extra storey Horizontal extensions New balconies			
Floor area before/after [m² - heated floor area]	458	657		
U of exterior walls before/after [W/(m²K)]	1.07	0.18		
Space heat demand + DHW before/after refurbishment	175	17.2		
Occupied during refurbishment	No			
Mounting equipment	Crane Scaffolding			
Façade modules				
Туре	Open TES			
Orientation	Horizontal			
Typical dimensions	Large (largest dimension = 10m)			
Type of adaptation layer	Blown-in insulation (main insulation)			
Anchorage configuration	Standing configuration Single-storey span			
Load transfer at building base	Base wood beam on brackets			
Building equipment & services	New windows (Uw=0.8) Solar blinds TES-connected (ventilation ducts)			
Module section				

		Exterior air			
ON	10mm	Plaster			
OFF	40mm	Insulation Board, Plaster base	Wood fibre		
OFF	Ś	Front panel	Fibre cement		
OFF		Structure	Timber studs		
ON	180mm	Insulation	Blown Cellulose		
ON	20-50	Adaptation layer	2.0111 00.000		
Existing wall					

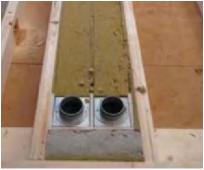


After



Off-site





On-site

