Case Studies – Adaptive Facade Network

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Case Studies

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Introduction

Marcin Brzezicki, Daniel Aelenei, Laura Aelenei, Rosa Romano, Enrico Sergio Mazzucchelli, Jose Miguel Rico-Martinez

Adaptive facades; Definitions and Technological Evolutions

Adaptive façades consist of multifunctional highly adaptive systems, where the physical separator between the interior and exterior environment is able to change its functions, features or behaviour over time in response to transient performance requirements and boundary conditions, with the aim of improving the overall building performance (Loonen et al., 2015). Furthermore, these envelope systems can seize the opportunity to save energy by adapting to prevailing weather conditions, and support comfort levels by immediately responding to occupants' needs and preferences (Loonen et al., 2013). In other words, adaptability can be understood as the ability of a system to deliver intended functionality, considering multiple criteria under variable conditions, through the design variables changing their physical values over time (Ferguson et al., 2007).

But, is it possible to find a single definition for the complex panorama of smart envelope systems that have characterized the contemporary architecture of the last decade? For years, architects and building scientists have envisioned the possibility that future buildings would possess envelopes with a certain type of adaptive response to changing environmental conditions. In 1975 N. Negroponte (Negroponte, 1975) introduced the concept of responsive environment, capable of playing an active role, initiating to a greater or lesser degree changes as a result and function of complex or simple computations. In 1981, Mike Davies proposed the idea of 'The polyvalent wall', an envelope system where several functions can be integrated into one layer (Davies, 1981). However, only in recent years, technological research has been investigating new experimentation frontiers capable of reaffirming the osmotic quality of a process of exchange that concerns energy flows that have passed and exchanged right through the envelope (Altomonte, 2008). These studies are new research to demonstrate if a vertical closure surface can be equipped with systems designed to ensure the dynamics required to the managed energy flows in the same way as a biological organism. From the screening system of the Arab World Institute by Jean Nouvel to the dynamic screenings of Al Bahar Towers by Aedas Architects, the new frontiers of innovation in architecture are oriented towards proposing new models of approach in which the "building organism" is also capable of autonomously ensuring the comfort of its users. In this sense, the evolution and dissemination of Information Technology Control (ITC) systems (from home automation to Building Management Systems (BMS)) to transfer the potential of systems equipped with artificial intelligence to the building scale, has ensured the regulation of space also in the absence of human users and in relation with a whole series of requirements that guarantee optimisation from the functional and physical perspective of the built space.

Therefore, adaptive façades can be considered the last frontier of contemporary architectural and technological research which is more and more related to the wish of designing new dynamic envelope models, which, with the help of sensors, system components for energy production and smart materials, contributes towards reducing the building's energy demand. These are technological solutions that, as previously mentioned, are capable of managing energy flows by altering the properties of fixed devices (smart materials) or by controlling (manually or automatically) moving parts (e.g. sunshades, windows, ventilation outlets, etc.) in relation to the type of user and complexity of the building. This envelope typology is marked by dynamic anisotropy that is the capacity to offer different solutions for the different exposures of the building, where a change in the structure modulates the various environmental flows according to the climatic conditions of the place, including external climatic-environmental conditions.

Given the complexity of the topic and multiple variables affecting the performance of these systems, in the collaborative frame of COST Action TU 1403 (http://tu1403.eu), a characterization was carried out in terms of technologies and purpose, as described in Figure 1, where the first column represents the purpose of façade/components with adaptive capacity, which can be related with thermal comfort, energy performance, indoor air quality (IAQ) and visual and acoustic performance, among other requirements.

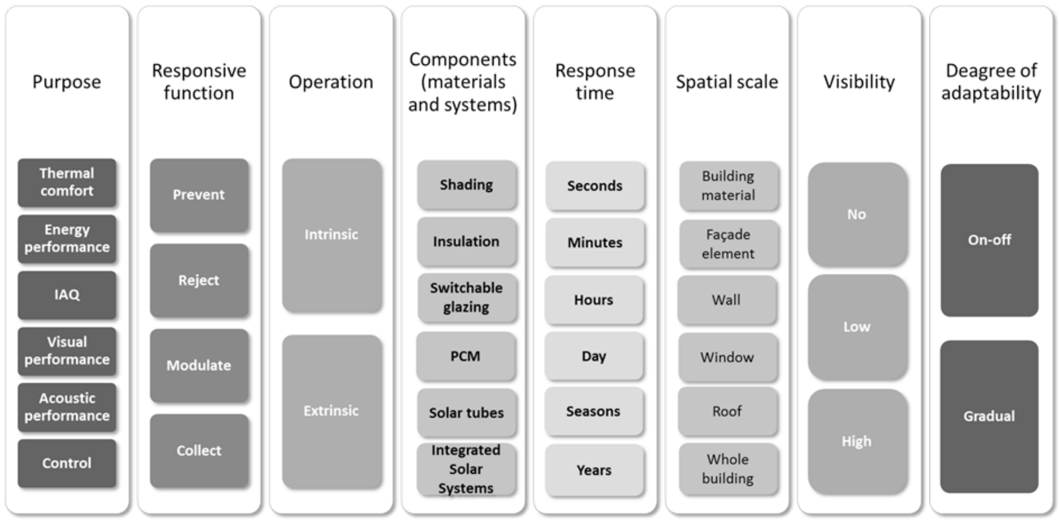

Figure 1 - Overview of characterization concepts for envelope adaptivity (adapted from Loonen et al, 2015)

Adaptive façade classification

The wealth of available adaptive façade technologies called for some systematic approach to recognize and study the façades properly. The attitude presented by the members of WG 1 was towards an analytic approach: the definition of higher rank structures within the façade (façade-systems) and recognition the lower-rank sub-structures: (components and materials) which made up the higher rank structures. This approach also allowed to study the sub-structures separately. In this regard, the database case studies were classified into three main groups, related to the following definitions:

- **Material:** a material can be in different states of refinements such as raw, extruded or coated. Also, materials that are inseparable combined, such as bi-metals, belong to his category. Examples of these types of material are: Polymer, Bi-metal, steel, wood, phase change material.
- **Component**: a component is an assembly of a different set of elements. It forms a complete constructional or functional unit as part of a façade. For example, we can define as component systems an insulated glass unit but also a window frame including glazing or a sun-shading device.
- **Façade-system:** a façade system is composed of different transparent or opaque structural or technical components. It fulfils all basic technical façade functions such as insulation, rain and wind tightness. Example of façade systems are: curtain wall; prefabricated module; double skin façade; ventilated façade, etc.

The conceptual diagram of the case study classification is explained in Figure 2.

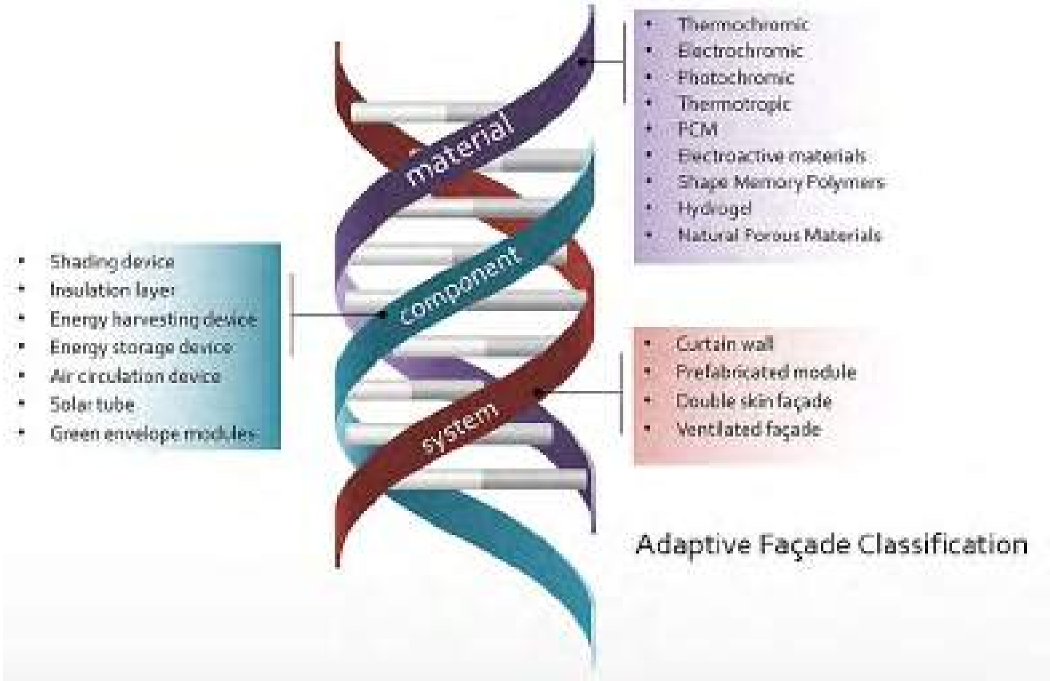

Figure 2 - Conceptual diagram of the case study classification

Case studies database

To study the adaptive façades a case studies database was developed within the frame of COST TU 1403 with the help of a specific online survey (structured in the following main sections: detailed description - metrics- characterization- economic aspects – references). The database includes 165 cases of the adaptive façade systems, components, and materials that allow conducting a variety of analyses. In the following, the results of simple analyses conducted with the objective to find the distribution of the main parameters described in Figure 1 across the case studies are presented. Survey was prepared using the https://www.easygoingsurvey.com/ mechanism, that was made available by School of Architecture of the University of the Basque Country, UPV/EHU.

Basic parameters. The most common entry was the AF System (41%), the AF Component and AF Materials being represented in approximately the same degree with 27% and 32%, respectively (Figure 3). In all the cases, where the area was specified, the majority of buildings are larger than 500 sqm (60%). In this group, the buildings larger than 5.000 sqm represent 34% of database feed (Figure 4).

Regarding type, the most common façade is the double skin façade (DSF) (30%) and prefabricated façade module (32%), while curtain walls constitute the remaining 32% of types (Figure 5). Double façades are popular since the beginning of the 1990s, with the peak in 2014, while e.g. the unitized curtain wall systems initialized in 2012, probably as a result of the CAD/CAM manufacturing systems rapid development.

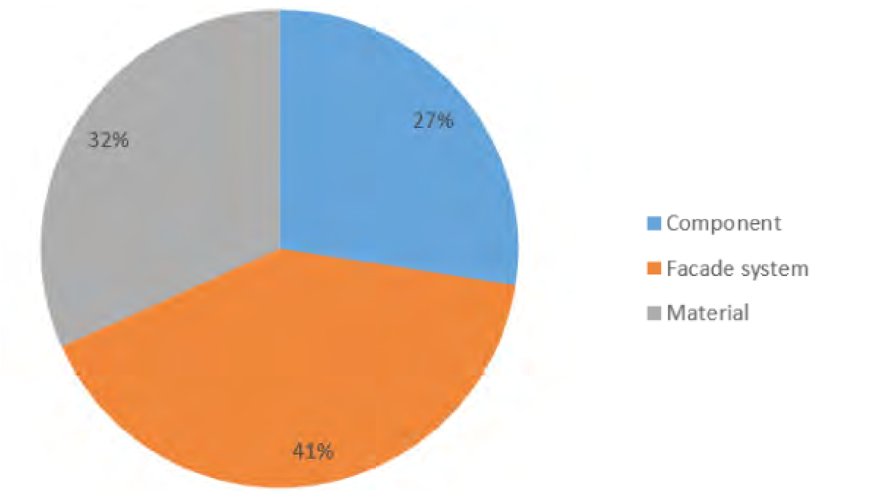

Figure 3 - Adaptive façade type

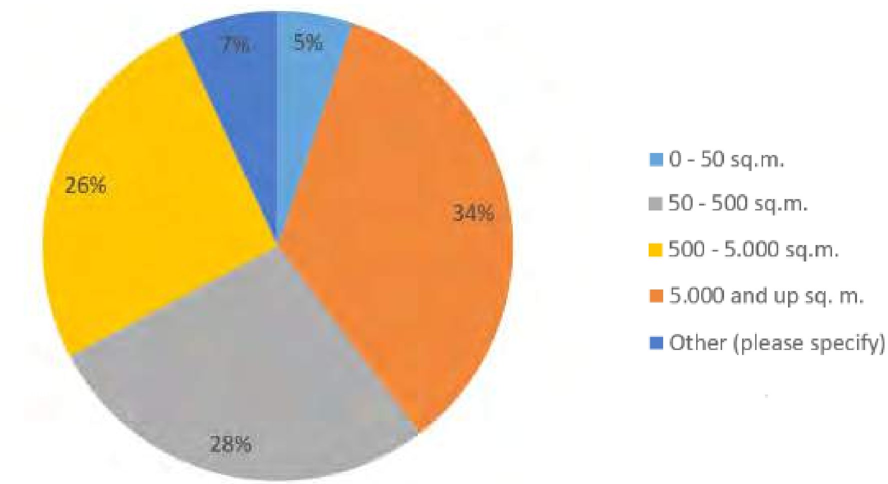

Figure 4 - Building area distribution

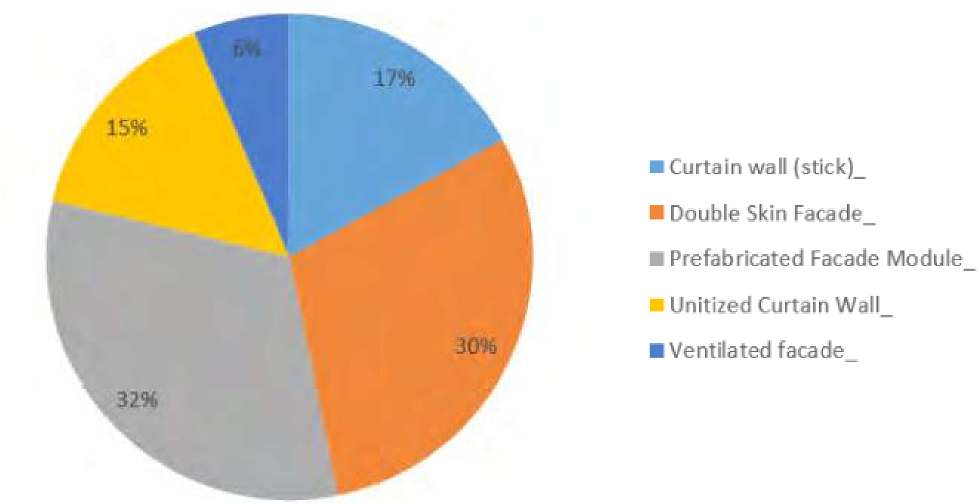

Figure 5 - Façade system type

Function/goal/purpose. With regard of purpose or function, the most frequent features in the façade were thermal (30%) and visual comfort (24%), with a substantial share of the "appearance" answer (16%) (Figure 6). These three inputs constitute over 70% of all entries. This shows that the heat gains and glare are perhaps the major problems in the sustainable design of office buildings because of the environmental cost of HVAC (Heating, ventilation, and air conditioning). The results also emphasize the importance of proper indoor temperature in the building. It could be argued that most entries in the "thermal comfort" category are mostly concerned with the summer performance when there is a significant risk of overheating. The same applies to the entries in the "visual comfort" category which is strongly connected with a glare.

Response time. Regarding response time, the most frequent entries are seconds (49% of cases) and minutes (38% of cases). Diurnal response time is present only in less than 2% of cases. This shows that a relatively fast reaction to the changing outside conditions in the most desirable function of the adaptive façade. This may also indicate that the most important factor that was optimized was insolation.

Another analysis shows that mainly thermal comfort and visual comfort (appearance) are optimized in the scale of seconds and minutes. This strengthens the conclusion that the most common change was the change in terms of centimetres, in order to optimize visual and thermal comfort.

Technology scale. The scale of technology is another important parameter showing development trends and, in this respect, the vast majority of solutions found in the database operate on a scale of "centimeters" (46% of cases). The second largest entry in this category is "nanometers" with 22% which corresponds to technological solutions such as coatings and smart glazing. The comparison of the scale of technology with the year of implementation of the system shows another strong dependence (Figure 7). From the beginning of the development of adaptive façade technologies (approximately in 1998) "centimeter technology" has been developing most dynamically until around 2015, when the share of this scale started to decrease in favour of scale of nanometers and millimeters as a result of coating development.

Technology response time vs. system visibility. Also, the juxtaposition of the "technology response time" and "system visibility" shows important features. 42% of entries shows that technology at the 4th level of visibility (visible change of size and shape like in shutters, flaps, dynamic façade elements) mainly responds in the temporal scale of minutes and seconds. In 12% of cases in total the reaction time was in seconds, but with no visible surface changes (e.g. 2nd level of visibility like in smart glazing) – see Figure 8. A similar relationship is visible between the "response time" and the "degree of adaptivity", where the gradual change concerns 83% of cases in total (the on/off change applies to 15% only). However, the gradual change in the temporal scale of the minutes and seconds applies to as many as 72% of all cases (Figure 9). This clearly shows what type of degree of adaptivity is the most common and in which temporal scale the change takes place.

Control operation type. Extrinsic (requires external control – 53%) and intrinsic (autoreactive – 47%) control operation types are almost equally present. Those two types of control refer in the majority to the technology scale in centimeters (46% of cases), while the intrinsic control is also present in the scale of nanometers (approx. 16% of cases). 53% of cases of both extrinsic and intrinsic control in total refer to the thermal comfort and visual comfort function of the façade. In 16% of cases, the responders also indicated the appearance of the façade – Figure 10.

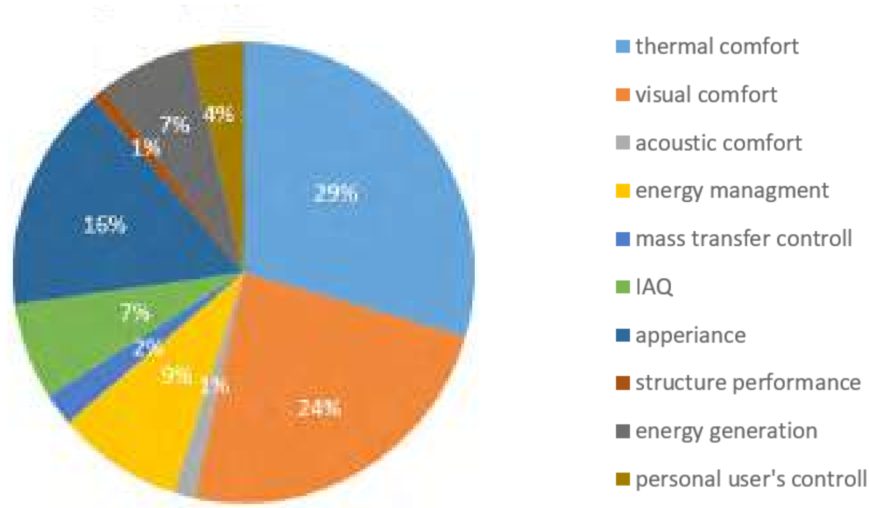

Figure 6 - Function/goal/purpose of the façade

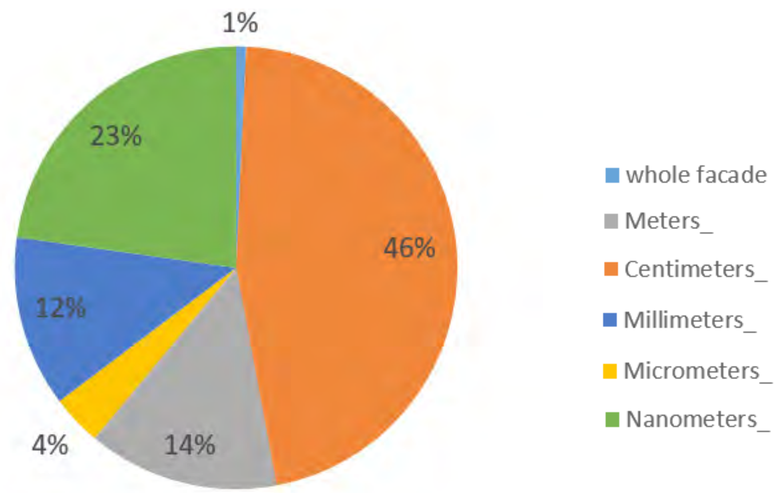

Figure 7 - Technology scale

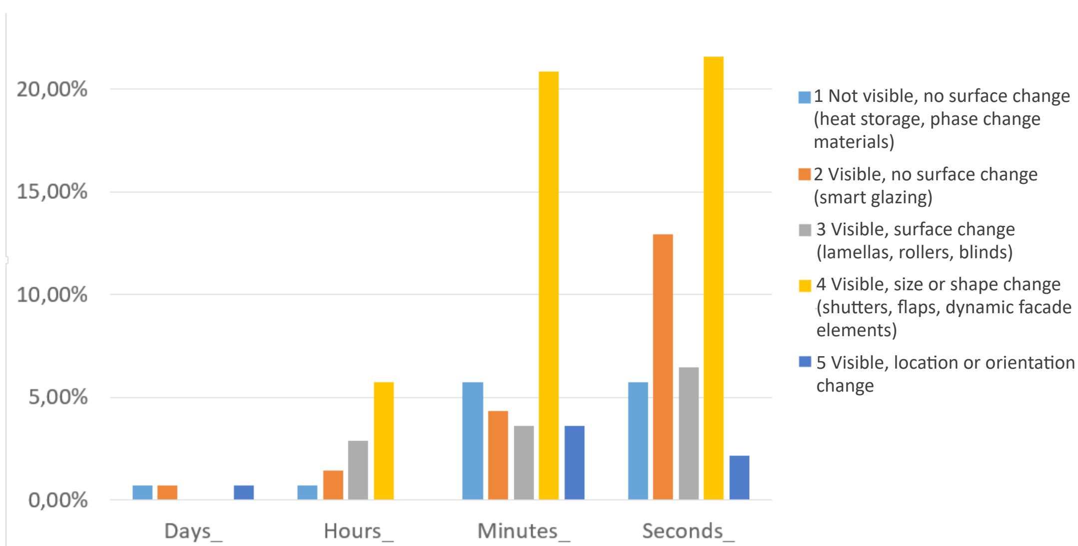

Figure 8 - The juxtaposition of the “technology response time” and “system visibility”

The estimated cost of the façade systems, components and materials. The exact costs of implementing AF technologies were not available to the researchers. Instead, individuals who participated in the survey were asked to assess whether these costs were high, medium or low. In 73% of cases, respondents indicated that the costs of the solutions applied were high, the remaining being divided between medium and low with 19% and 8%, respectively. This means that AF technologies are perceived as expensive, with particular emphasis on the high costs of façade systems, as described in Figure 11.

Map

Throughout the span of the action, WG1 gathered a lot of valuable information including database entries and state of the art on the subject of adaptive systems. Information was available in various databases and formats; the entries were made by different bodies and from different perspectives. The abovementioned information needed verification, master processing, harmonization, and generalization. Existing database was consolidated and reviewed. Missing or improper information was filled.

One of the most important issues in the database created for WG 1 was the establishment of the geographical location of the entries. Climate zone has a profound influence on the adaptive façade solutions that are used in the buildings. It determines the amount of sunlight or e.g. the potential to use sustainable passive technologies like night ventilation and cooling. The map (https://batchgeo.com/map/5487a71fd294c2f8481412c474bcd668) allowed to visualize the location of the entries from the database.

The map is a link between the façade location and the database. Provides the exact geographical location of the building. The map aims to visually determine the location of buildings in space.

Technical map processing. Initially, a modified spreadsheet was created with geographical and web-orientated data. The map was created based on the "batchgeo.com" mechanism that allows for the display of different types of data and for the graphical intuitive data grouping. Case studies were illustrated and linked to the simplified data-sheets that are located on the COST TU 1403 action share point server and are publicly available. The database was prepared, edited and uploaded to batchgeo.com mechanism to prepare professionally working location map of case-studies (encoded with location) or technologies (encoded with inventor's location) with possible grouping options: type; year; climate.

Map Layer Descriptions. Each point in the map has a label featuring the basic data description: the name of the building, the name of the designer, year of construction, link to the designer's web page.

The layer list allows users to select which map layers are visible and active (see Table 1, Fig. 12).

Map scrolling. After scrolling the map the visual representation of all featured case studies will be visible in rows, with the links active. This overview allows seeing all the buildings in a much more accessible form, than on the map.

Map content and conclusions. Some generalization is possible based on the cases gathered in the map. The case studies illustrated on the map are mostly grouped in Central Europe, with some

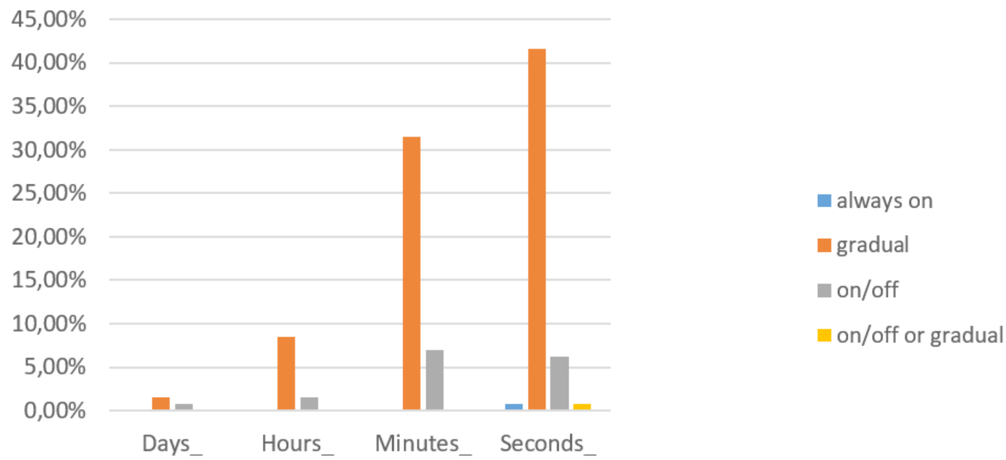

Figure 9 - System degree of adaptivity

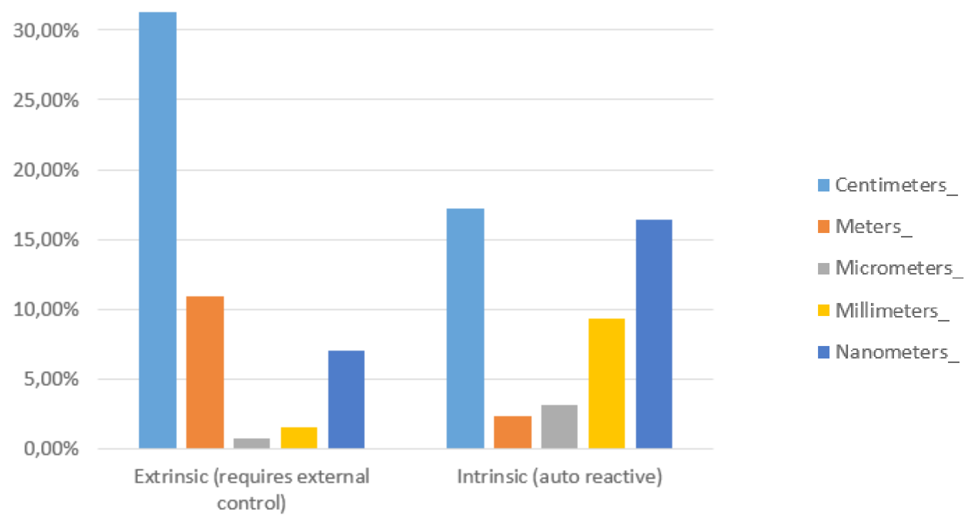

Figure 10 - Control operation time

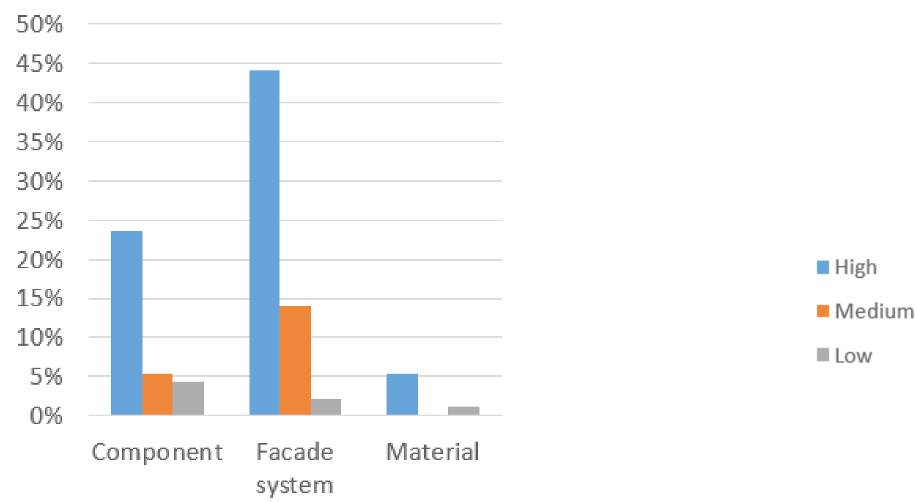

Figure 11 - Estimated cost of the façade systems, components and materials

cases in Scandinavia and the Iberian Peninsula. Some case studies are also located in USA, Middle East, and Asia. The biggest number of case studies is located in Germany (16 case studies). This results in two conclusions:

- The first conclusion is that in wealthy countries with a stable economy and high GDP investors are more likely to implement experimental solutions in buildings, with the emphasis on office buildings. In these countries also, the investment to improve the office rooms user's comfort pays back in a shorter period of time.
- The second conclusion is that adaptive façade solutions work best in the temperate climate zone, where high seasonal temperature variation calls for the use of technologies that adapt to changing climatic conditions – 25% of buildings in Cfb climate (Temperate), and 14% in Dfb climate (Cold continental). Admittedly, in desert climate zones significant seasonal differences in temperature (25-45 °C Jan to Aug) is present, but even in the mildest period of the year temperatures are too high to effectively cool the building through ventilation. In climates where climatic conditions are characterized by low seasonal variability, the use of adaptable façades has less rational justification.

An important conclusion from the map preparation is the ability to precisely locate individual buildings. From the map, it can be clearly seen that most of the buildings are located in city centers with a population of more than 100,000 inhabitants. Especially many buildings are located in the county's capitals, such as 5 buildings in Berlin and 3 in Paris. It is also interesting that the majority of AF Systems in newly built buildings are oriented to the South (75%), which shows that heat gains and glare are the biggest problems in the sustainable design of office buildings because of the environmental cost of HVAC. The database data shows that thermal comfort and visual comfort was the basic main reason for the adaptive façade system in 53% of buildings.

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Table 1 - List of map layers for the basic data description

Name:	Building's name
Location	Exact GPS location of the building. In the case of the material, the location of the institution is given.
Designer or researcher	In the case of the building: name of the designer researcher In the case of the building: name of the designer researcher
Year of construction	Year of construction
Type of entry:	Type of database entry: AF System, AF Component or AF Material
Climate:	Type of climate
Web-link	Provides the link to the designer's webpage

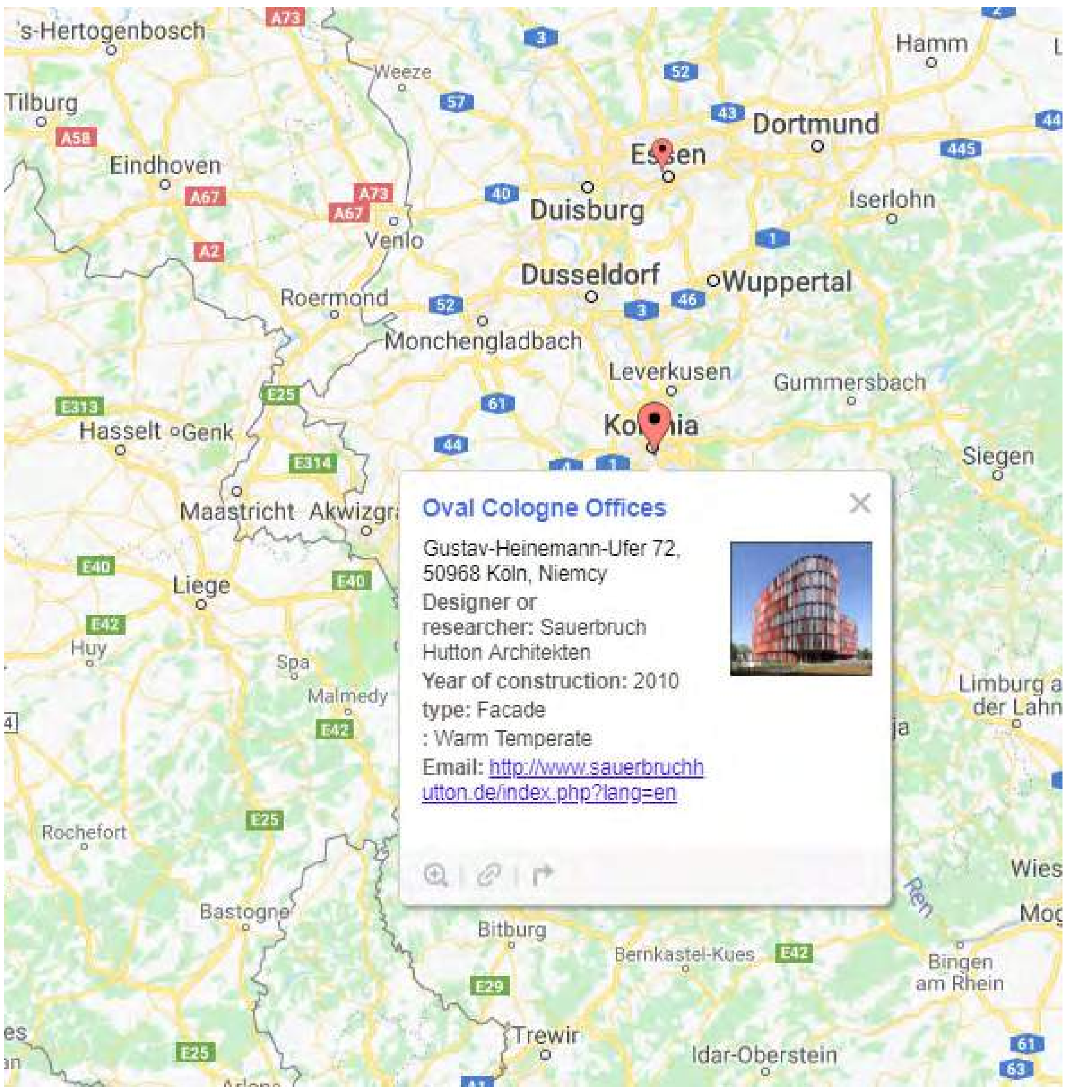


Figure 12 - The tag in the map showing the detailed information about the case-study

Acronyms

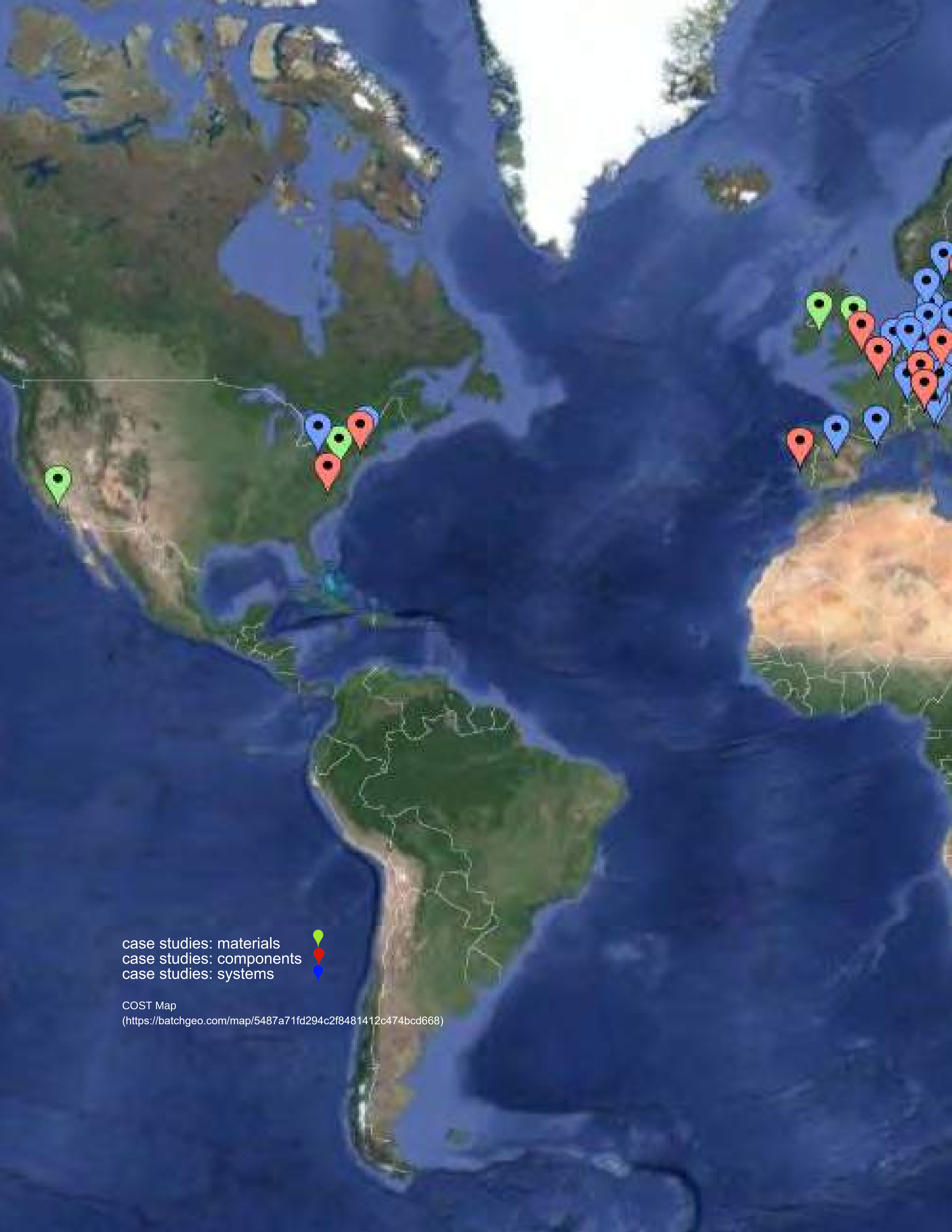
CW	Standard Curtain Wall
ATF	Active Transparent Facades
SG	Switchable Glazing
PCM	Phase Change Materials
MFM	Multifunctional Facade Modules
BF	Biomimetic Facade
AF	Adaptive Facade
CS	Case Study
SMA	Shape Memory Alloys
TIM	Transparent Insulation Material
PTFE	Poly Tetra Fluoro Ethylene
EC	Electro-chromic
SPD	Serial Presence Detect
SDR	Software Defined Radio
CA	Cellular Automata
NN	Neural Networks
EAP	Electro-Active Polymer
CFD	Computational Fluid Dynamics
HVAC	Heating, Ventilation and Air Conditioning systems
TVG	Through Glass Via
SGP®	Sentry Glass Plus
FFG	Fluid Flow Glazing
DSSCs	Dye-Sensitized Solar Cells
NITI	Nickel Titanium
SME	Shape Memory Effect
SE	Super Elasticity Effect
ICCP	Current Cathodic Protection
HEMN	Hydrogel- Embedded Micro-vascular Network
PoDM	Photosensitive organic dye molecules
ETFE	Ethylene Tetra Fluor Ethylene
BIPV	Building Integrated Photovoltaic
ESD	Electro Static Discharge
LED	Light Emitting Diode
UFAD	Under Floor Air Distribution
nZEB	nearly Zero Energy Building
PV	Photovoltaic
EURAC	European Academy
EPFL	École Polytechnique Fédérale De Lausanne
ICTC	Information Communication Technology Centre
IBA	International Building Exhibition
RGB	Red Green Blue
NIR-VIS EC	Spectral Reflectance Measurements Acquired In The Visible (Red) And Near-Infrared Regions
IGU	Insulating Glazing Units
R	Resistance value
°F	Fahrenheit Degree
CO_2	Carbon Dioxide
SELFIE	Smart and Efficient Layer for Innovative Envelope
DE	Germany

IT	Italy
USA	United States America
FR	France
PT	Portugal
DK	Denmark
ROK	South Korea
CH	Switzerland
ES	Spain
AT	Austria
SE	Sweden
FI	Finland
AUS	Australia
CN	China
SE	Sweden
S	South
S-E	South East
S-W	South West
N	North
W	west
N-E	North East
N-W	North West

Climate Type Acronyms from Köppen Climate Classification System (http://www.eoearth.org/view/article/162263/)

Af	tropical rainforest climate
Am	Tropical monsoon climate
Aw/ As	Tropical wet and dry or savanna climate
BWh	desert climate
BWk	Cold desert climates
BWn	Mild desert climates
BSh	Hot semi-arid climates
BSk	Cold semi-arid climates
Csa	Hot-summer Mediterranean climate
Csb	Warm-summer Mediterranean climate
Cwa	Humid subtropical climates
Cwb	Subtropical climates
Cwc	Highland climates
Cfa	Humid subtropical climates
Cfb	oceanic climate
Cfc	oceanic climate
Dsa	Humid continental climates
Dsb	Humid continental climates
Dsc	subarctic climate
Dsd	subarctic climate
Dwa	Humid continental climates
Dwb	Humid continental climates
Dwc	subarctic climate

Dwd	subarctic climate
Dfa	Humid continental climates
Dfb	Humid continental climates
Dfc	Humid continental climates
Dfd	Humid continental climates
ET	Tundra climate
EF	Ice cap climate


case studies: materials
case studies: components
case studies: systems
COST Map
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