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Research paper

An investigation of the potential of dematerialization to reduce the life cycle embodied energy of buildings

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Abstract: One of the basic requirements of the paradigm of sustainable architecture is the use of materials and building systems characterized by low embodied energy. The aim of this paper is to examine the problem of rational design for lower embodied energy of building components and details. To raise the suitable competence of building professionals and stakeholders, the paper recommends some ways of approach to these issues. The reduction in the quantity of applied materials, so called dematerialization, the use of low energy materials for construction, reduced maintenance works, less frequent exchange of components and materials during the building operation, and their higher durability lead to better results in this regard. Some exemplary practical applications of such approach to design of contemporary buildings using the state-of-the art technologies, which strive to be in line with the requirements for sustainability, as well as some other being contradictory to them, have been covered in this paper.

Keywords: building's durability, building technologies, sustainable technologies

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1. Introduction

A basic principle of the paradigm of ecological construction is the use of adequate methods for planning and erection of low energy buildings. Mostly considered are the construction technologies as well as the operational performance of buildings. The majority of published research works in the field have focused on the latter issue [1, 2], whereas the concept of addressing embodied energy, some- times called also "grey energy" [3], is not as advanced within the industry [4]. This encourages to further research enhancing the body of knowledge in this area. The embodied energy used in a building's construction is called initial embodied energy (IEE), whereas the energy embodied in the recur-ring process of maintenance, repair, and replacement is termed recurrent embodied energy (REE). To effectively optimize a building's life cycle embodied energy, both the REE and IEE must be evaluated collectively [5]. Building energy research has concentrated more on operating energy than embodied energy [6]. Focusing research on embodied energy instead can be justified due to many authors, who claim that the environmental impact of a building will presumably shift from the operation phase to the construction, maintenance and return of building materials to the material cycle, in the future [7].

External building facades, internal partitions and suspended ceiling, which form an integral part of building structures, are currently characterized by a very high embodied energy [8]. Regardless of the project type and location, many previous studies have highlighted the significance of material phase impacts [9]. In particular, they emphasized the importance of building frame and envelope design to help reduce initial embodied energy consumption [4]. This complex problem refers not only to the recommended application of low embodied energy materials, but also to low energy methods of their installation in buildings [3], dismantling, and eventually recycling and utilization.

There are efficient methodologies for calculating embodied energy and carbon of buildings [10–12]. Every methodology has its own advantages and limitations, so it is very hard to suggest the one superior and suitable to assess embodied energy [13]. The users should understand uncertainty and imperfection of their evaluation, if they follow a certain methodology [13–15]. The need for a reliable assessment is tied to the development of high performance buildings that integrate and optimize energy efficiency and life cycle performance; shifting the focus to the reduction of building operational energy makes embodied energy a significant part of a building's life cycle [16, 17]. It is also important to evaluate the operational lifetime and maintenance requirements of building materials to enable the construction of true low embodied energy and carbon buildings [18]. However, there are some obstacles in a reliable assessment of embodied energy in materials. Some sources indicate that it is important to remain skeptical about what is published concerning figures in embodied energy databases [19]. In this regard, design choices made by architects are not a simple and easy task. A very high initial embodied energy may not be crucial in the case of a material, which is extremely durable and will not need replacing for many years. Its use would be preferred comparing to other materials that have lower initial embodied energy values, but may need to be replaced much earlier [20]. The durability of building materials have a significant impact on the buildings' service life and on its embodied energy [21]. Increasing building service life can reduce embodied energy by up to 29% [22]. The problem is of high importance, as this form of energy is responsible for about 20% of the total energy used in facilities in their life cycle [20, 23]. It is very difficult to predict long-term energy costs. Also the calculation of a whole-life cost is difficult to predict accurately and leads to skepticism [24].

The guideline for designing teams leading towards the lowering of the quantity of embodied energy can be implemented in many ways. The simplest method for reducing it in buildings is a careful choice of building materials based on the lowest possible value of this parameter. Preferable in this regard are regrowable resources, which should substitute abiotic materials. One of the rules of thumb indicates that the higher the cost, in general, the greater the embodied energy [25]. Another possibility offers the product optimization. It consists in an alternative use of better quality materials featuring, for instance, higher load-bearing capacity, or are lighter than conventional [7]. A good choice is the use of written sources featuring green building materials. A relatively easy and recommendable option is the use of building materials in lower quantities, and manufactured or sourced close to building sites. This procedure is defined as dematerialization [26]. The term comprises also an indication as to the choice of materials, which will ensure their maximum possible durability, as well as that of the construction systems which they form. This would reduce the frequency of their necessary substitution, and as a result, it would lead to a frugal use of building materials in the buildings' life cycles. The maintenance works carried out only sporadically would also contribute to the effective saving of preservative compounds. It is, then, another method of dematerialization and the reduction in energy used during the process of construction and operation of buildings.

Dematerialization, being one of the basic strategies in sustainable design, can be then considered in three ways: through the reduction in quantity of materials used in construction, suggestions concerning the design for more rational maintenance of building components, and through the less frequent substitution of installed materials in building.

The issue of embodied energy in building materials and technologies is usually not explored extensively, and the research results are not taken into account by the majority of designers. It is rather seen as a theoretical and not a practical problem. The scientific and professional literature covers mostly the first aspect of energy in buildings, and only marginally that of embodied energy [3, 27, 28]. The significance of this issue is ignored intentionally in some sources, which claim that embodied energy is responsible only for 10%, or in some cases 2% of the total energy consumption, so this number is incomparable with the operational (energy in use) used in buildings [19]. A similar approach to this issue can be found within the most popular building certification systems, which usually are mutually incompatible [29, 30]. As opposed to that, other sources indicate that in recent time the operational energy has been reduced (in dwellings) and the relative impact of embodied energy has increased [31]. Given these uncertainties, this research is in favor of the latter opinion, as it is more recent. Many published sources emphasize that it is embodied energy which represents the highest energy consumption in all variations [32].

2. Methods

The relations between the implemented technology and relevant embodied energy is usually not considered in an everyday design practice. As a result, defects and faulty energy-related solutions can be easily found in buildings. There are some general indications and recommendations in this regard [33]. However, a good practice should also be based on the learning from constructed buildings of low performance due to faulty details and technical solutions. It is hardly possible to predict an acceptable performance of every detail of a building at the design stage on the basis of meeting general rules for sustainable solutions [34]. Therefore, every case of a relevant building offers a very good opportunity to enhance the knowledge of designers in this regard.

The research method used and described in this paper is based on an ex post evaluation of designs and buildings through participatory observations [35]. They consist in descriptive analyses of various aspects [36] of the issue of embodied energy in materials and elements of selected buildings. On the basis of “in situ” observations, it was possible to use deduction and logical interpretation of the obtained results thereafter. The research was also intended to find out whether the “state-of-the-art” technologies applied in some buildings feature underlying conscious design choices in view of embodied energy-related ideas. In order to analyze this problem, the case study method was applied, as it is a proper and highly evaluated technique used in architecture. As R. Foque claims, case study research can contribute to the elaboration of architectural design theory, which in turn can stimulate adequate effective design choices to avoid faults [37]. Assumptions had been made that the analyzed cases should take into account a possibly wide scope of diverse building functions, locations and building cultures. Qualitative research methods allow to check the extent to which an examined building meets the requirements set in terms of specific qualitative criteria.

The work does not analyze quantitative aspects or building components related to the values of embodied energy, except for some comparative cases. It has been assumed, that given the everyday architectonic practice, the issue is as a rule not yet analyzed by architects, concerning the building’s particular components, especially building details. Therefore, the research does not concentrate on the quantities of embodied energy in the analyzed building parts, just as it is in everyday architectural practice. It suggests that it would be a good practice to analyze building details and components in view of energy problems, even without producing suitable calculations, as they would be very difficult to carry out with no specialized professional assistance. Such an approach based on simple deduction is presented in this research.

A case study method was applied separately to the three following dematerialization problems:

1) reduction in the quantities of installed materials associated with *initial embodied energy*,
2) reduction in the frequency of maintenance works impacting the recurring embodied energy,
3) reduction in the frequency of replacements of materials determining *recurring embodied energy* [38].

There are 3 cases of analysed buildings in each of the 3 groups, with 2 exceptions. It is not intended to compare the analysed buildings in their every technical aspect in this research, but rather to indicate their building solutions in relation to embodied energy. Therefore, both their functions and locations, as well their building components are not interrelated, and they do not exhibit a defined pattern. The locations of considered buildings in the moderate climate zone have been randomly chosen in Europe to show that the identified building faults, or rightful solutions, can be found anywhere, and the particular characteristics of their locations are irrelevant in this regard. The method used comprises a careful observation of details and combined building systems, as well as a later in-depth analysis of damaged or deteriorated materials, their neighboring areas, discolorations, fixing systems, etc. This procedure was intended to reveal the deduced causes of negative processes that had taken place in particular buildings.The exemplary buildings or their components are characterized by:

- untypical materials and solutions in the cases of the first group concerning the dematerialization through the reduction in quantities of materials,
- conventional materials and technologies in the second and third group concerning the dematerialization through the reduction in maintenance works and frequency of replacement of materials.

It is the building envelopes, and in particular facades, which are analysed in this study because their construction methods are basically responsible for the durability and technical performance of buildings – including initial, and recurring embodied energy, as well as operational energy.

3. Dematerialization through the reduction in the quantities of materials

Dematerialization should be considered at the design stage, if it is to be implemented through the reduction in quantity of materials used in construction. Façade technologies should be a primary target in this regard, as they require a major material input during construction works. The quantities of materials in buildings can be reduced in various ways, like:

A) replacement of some components made with traditional materials and conventional thicknesses, with thinner structures, if possible;
B) use of modified technologies that allow for resignation from some layers within combined elevation systems;
C) use of unconventional solutions permitting to eliminate certain building elements, e.g. fixing anchors.

The following examples give ideas about how such solutions can be employed opening thereby new perspectives for the application of low material building systems. These experimental technologies usually bring positive dematerialization effects. However, some of them display negative unpredicted outcomes playing thereby a significant educational role.

Case A1. A good example of the first method is the Unilever headquarters in Hamburg, the building in which the glass of the outer leaf of double facades, being usually a standard situation, has been replaced with ETFE foil. As being lighter (thinner) than glass, this material permitted to make the steel frame support of the outer leaf of double facade less robust, and using lower quantity of structural steel (Fig. 1). The use of membrane material potentially reduces the weight of a building structure per square meter. This applies to roofs, but also to the building envelope, i.e. facades [39]. The ETFE system weighs between 10% and 50% of the conventional glass façade structure including aluminium connection and steel frame support [40]. Embodied energy value of the ETFE foil per weight of material (210 MJ/kg) is more than ten times that of the glass (18.6 MJ/kg) [41]. Comparing the two materials, that is 6 mm-thick float glass panel, which is characterized by the 300 MJ/m2 [40] embodied non-renewable primary energy [40], to the employed ETFE foil with the value of 27 MJ/m2 [40], it can be clearly seen, that the latter features much lower embodied energy value offering relatively long useful life expectancy [27,39]. Moreover, the steel structural system supporting the lighter outer leaf and fixing [3] is also lower in embodied energy than it would have been in the case of glass applied. This is the reason for which the ideas for dematerialization should be analysed not only from the point of view of embodied energy in a given material or system, but also through the comparison of the quantities of alternative materials used within a given building technology. The analysis of this case has indicated differences in the values of built-in energy parameters drawn from various databases for the analysed materials. Such discrepancies can substantially impact the final results. Therefore, these values should be carefully considered and consulted in several sources prioritizing the recent ones.

Case A1	
Building	Unilever Headquarters, Hamburg, Germany
Conventional technical solution unused	6–10 mm exterior glass panel glazing; Steel framing supporting external structure; Aluminium framing or stainless steel spiders and fixing bolts;
Alternative implemented solution in analyzed building	ETFE foil; Economical thin steel supporting structure
Dematerialization effect	Reduction in quantity of overall initial embodied energy through elimination of high embodied energy materials
Reported faults	None

Fig. 1. Unconventional façade technology for dematerialization. Unilever Headquarters, Hamburg, Germany

Case A2. Another approach to the problem has been exemplified in a youth culture centre in Amsterdam. A two-layer wall structure with a sprayed polyurethane foam insulation, as exterior finish, make the system (Fig. 2). It eliminates the need for the installation of a third protective layer which, depending on the system, usually entails a necessity for an energy consuming steel or aluminium substructure to support a finish panel material. Such a ventilated façade would employ a mineral wool layer that would be almost twice as thick as the applied material to display a comparable U-value. A similar situation would occur with an alternative conventional solution with the rendered Styrofoam panels. The method applied undoubtedly reduces the amount of materials used. However, the embodied energy of polyurethane foam is higher than that of each alternative material, as proves the comparison of recalculated values of embodied energy, allowing for one square meter of wall surface, based on the following data: 130 MJ/kg for polyurethane foam, 125 MJ/kg for Styrofoam, and 17 MJ/kg for mineral wool [42]. But there is another parameter, which despite the apparent negative outcome, seems to make the system sensible. It is much lower U-value achieved by the use of polyurethane foam in this composite wall [8].

Case A2	
Building	Youth Culture Center De hood Osdorp, Amsterdam, The Netherlands
Conventional technical solution unused	Insulating panel on massive wall and plaster finish or alternatively panel finish on steel anchors
Alternative implemented solution in analyzed building	Polyurethane foam 12cm sprayed on massive wall and anti-UV layer
Dematerialization effect	Elimination of steel anchors and finish cladding with panels
Reported faults	None

Fig. 2. Unconventional façade technology for dematerialization. Youth Culture Center. Osdorp, Amsterdam

Case A3. An noticeable implementation of the dematerialization idea can be seen in the case of an office building in Amsterdam, where the potential quantity of building materials to be used has been substantially reduced by the elimination of a standard mechanical fixing system of the exterior finish. It is one-story high, vertically applied long polycarbonate panels, which had been fixed to the building structure only by way of horizontal metal profiles at their ends. The solution used mineral wool panels as insulation between the structural wall and the PC panels. Low embodied energy of the applied technology resulted from the use of relatively low-embodied-energy insulation, and from the avoidance of costly fixation system. However, the modification of the conventional method used has not proved reliable in this particular case. The insulating rockwool panels, arranged in horizontal rows, unexpectedly subsided forming bulges at the joints between upper and lower panels. It can be clearly seen from outside through the greenish translucent polycarbonate panels. Thermal parameters of the exterior wall have been certainly compromised thereby (Fig. 3). It can be deduced, that the rock-wool panels have been deformed by their heavy weight. It occurred due to the application of long flexible polycarbonate panels, which yielded under the pressure exerted by the wool, then buckled, and made some space permitting the insulation to deform. Deformations of the PC panels were particularly significant on the south façade, which is subject to intensive insolation. Elongation of the panels and increased warm air pressure by the greenhouse effect within the wall structure added to the final disadvantageous result. Such embarrassing situation had certainly not been predicted in the phase of technical analysis and the design decision taking.

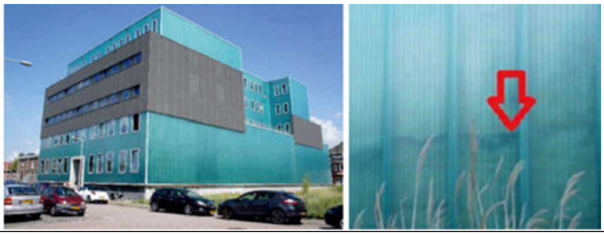
Case A3	
Building	Office building, Amsterdam, The Netherlands
Conventional technical solution unused	Wall structure with insulation, steel anchors, aluminium profiles, polycarbonate panels
Alternative implemented solution in analyzed building	Mineral wool mats on massive wall; Horizontal aluminium profiles; Polycarbonate panels fixed to high wall on ends
Dematerialization effect	Elimination of steel anchors
Reported faults	Down sliding insulation and uneven thermal transmission through wall

Fig. 3. Unconventional façade technology for dematerialization. Office building, Amsterdam

4. Frequency of maintenance works

Maintenance is defined as "routine work necessary to keep the fabric of a place in good order. In other words, the main objective of maintenance is to limit deterioration [43]. From the embodied-energy point of view: the less frequent maintenance works are, and the longer temporal intervals between them, the more advantageous the considered technical solution is. This increases also the dematerialization effect through the lower quantity of materials used. The low frequency of maintenance operations depends on the following features:

- optimum choice of materials for a given location and climatic factor,
- adequate mutual configuration of building materials and components,
- appropriate initial installation of building components,
- avoiding the use of technologies and materials vulnerable to potential mechanical damage by vandalism
- high durability of materials.

There are some other specific requirements for facade subsystems that should be appropriately found in the maintenance plan during the design phase [44]. The following examples will present these cases of buildings, where the failure to respect above-mentioned recommendations was the cause of unanticipated and unwishful features that increased the embodied energy of building components and countered the dematerialization idea.

Case B1. Failure to respect the above-mentioned recommendations can be seen in buildings on many occasions. It leads to the appearance of conspicuous defects in building envelopes. A good example illustrating negative aspects of a false choice of facade material for a humid and windy location may be the building presented in Fig. 4.

Case B1	
Building	Residential building, Amsterdam, The Netherlands
Building component	Exterior finish
Material	Wood
Negative process	Irregular staining of siding by rainwater due to disadvantageous mutual configuration of balconies and siding
Negative consequences	Frequent replacements or refurbishment of siding; Accelerated negative aesthetic appearance
Proposed alternative solution at design stage to reduce maintenance	Careful studies of local wind direction and disposition of balconies on facades. Use of wood cladding more resistant to weathering

Fig. 4. Façade with wood cladding stained by rainwater. Residential building. Amsterdam

The use of wooden cladding, characterized by low embodied energy, has brought negative effects in the form of spectacular damp patches and leaching of wood preservatives. That was the result of a faulty analysis regarding the potential impact of local climatic factors on the performance of the facade, as well as the character of mutual spatial configuration of balconies and the facade material, which turned out to be detrimental. It is noteworthy that an important role in the overall embodied energy input, given potential later maintenance works, plays the presence of balconies, of which the form, construction and detailing should be seriously taken into consideration at certain locations in view of wind directions. The substitution of facade materials at that stage of the operation of a building, as well as the application of maintenance procedures with the use of proper chemical compounds would require an additional energy input and the increase in embodied energy of building components.

Case B2. Stone cladding of a façade is shown in Fig. 5. It features some parts of the exterior wall with patches of dust deposits washed off by rainwater exposing clean areas of stone hexagonal panels. This case highlights the necessity for maintenance cleaning works carried out on a regular basis. Even preliminary rough analysis of this situation indicates the inadequacy of the material choice made by the designers. The location of the building at the corner of busy streets and the settling of rising dust on the facades lies at the basis of that ongoing process. Rains washing the flat facades have made a fancy irregular pattern appear in their lower parts, which are particularly vulnerable to dust deposits on the porous travertine surfaces in the proximity of street level. Due to the height of the building, cleaning works of the façades would incur some regular expenditure and involve the input of recurring embodied energy to regain their original aspect. This operation should be done, first of all, for the aesthetic reason rather, and not for technical. However, in some cases such unanticipated ageing of facades can be tolerated and accepted for untypical aesthetic tastes. Such unconventional approach would reduce maintenance operations lowering thereby the recurring embodied energy input by using less material.

Case B2	
Building	Commercial Center, Rotterdam, The Netherlands
Building component	Exterior finish
Material	Porous stone
Negative process	Settling of dust deposit and rain-washing
Negative consequences	Negative aesthetic appearance; Possible replacement of stone panels
Proposed alternative solution at design stage to reduce maintenance	Careful selection and application of nonporous stone materials

Fig. 5. Façade stone cladding deteriorated by rainwater and dust. Commercial centre. Rotterdam

Case B3. The example of building components shown below refers to the case of water as a degrading factor. This environmental factor, and its aggressive vapours, can frequently and sometimes unexpectedly exert an important negative impact on building envelopes. This leads to costly and frequent maintenance works entailing recurrent embodied energy input. Fig. 6 shows an example of exterior metallic elements, where the proximity of water caused their visible degradation of aesthetic and technical values. In the example B3, the exposed structural member of a building located in a very close proximity of seawater in the warm Mediterranean climate seems to be a dubious option. Moreover, the structure is affected by the water vapor rising from a water pool located directly below it. Even more than the previous one, this building is subject to costly repainting, which would secure the structure from the excessive and accelerated rusting process. A related recurring embodied energy input would be very significant to keep the building's aesthetics and its reliable technical performance in an acceptable condition.

Case B3	
Building	Hotel Arts, Barcelona, Spain
Building component	Exterior structure
Material	Painted steel
Negative process	Corrosion
Negative consequences	Need for frequent repainting of steel members
Proposed alternative solution at design stage to reduce maintenance	Avoidance of direct exposition of exterior steel

Fig. 6. Negative impact of environmental factors on exterior building elements. Rust on exterior structure. Hotel Arts, Barcelona

5. Frequency of replacement of materials

Replacement of the components installed in a building with new elements and materials increases its total life cycle embodied energy. Such an operation may occur for different reasons, like: me-chanical damage, accelerated weathering process, purposeful staining of vulnerable finish surfaces, faulty fixing systems etc. Certain attempts to carry out reparation works can sometimes improve the building's technical condition, but they rarely bring satisfactory aesthetic outcomes. In most cases, the damaged element requires replacement. This is an inseparable requirement of sustainable design: an in-depth analysis of every designed building component in view of its uncomplicated disassembly and replacement. Multi-layer elements should be manufactured to make it possible to separate.

As a general rule, we can enumerate factors that influence the future need for replacement of materials in buildings and their parts. These are:

- low durability of materials
- inadequate shape of components and their details vulnerable to damages
- location of components in places exposed to mechanical damage intentional or accidental
- exposure to intensive destructive action of aggressive climatic factors
- faulty system of components' fixing to building structure.

The following examples refer to such situations.

Case C1. Stone cladding panels are mostly fixed to structures by anchors. They appear to be very vulnerable in such applications frequently displaying spectacular signs of deterioration done by climatic factors, or human-induced mechanical damages. Point anchor fixing of stone panels is a technical solution that frequently results in the material chipping off under mechanical load at those vulnerable spots. As seen in Fig. 7, neither sort of conventional anchors offers a good performance in this regard. Relatively good effects are obtainable by the use of back-mounted steel dowels distanced from the edges of panels. However, this technology requires the application of hanging system on railings, which employs significant quantities of materials with high initial embodied energy. Presumably, a better solution would be the application of thicker panels than those usually used. A careful analysis should be carried out to explain, which of the two options bring better results in terms of embodied energy and dematerialization paradigm.

Case C1	
Building	a – Tete Defense, Paris, France; b – Residential building.Rotterdam
Building component	Exterior finish
Material	Stone
Negative process	Exposure of steel anchors by stone pieces chipping off
Negative consequences	Possible falling off; Water penetration inside wall structure; Unaesthetic appearance
Proposed alternative solution at design stage	Application of thicker stone panels; Anchors fixed on the back surface of panels; Mortar setting for panels close to ground level

Fig. 7. Damaged stone panels and exposed steel anchors (a – Tete Defense. Paris; b – Residential building, Rotterdam

Case C2. An example of metal sheet application shows in the following cases that this material is vulnerable to deformations in certain situations. The building's exterior finish in Fig. 8 was made with satin-finished metal sheets. In the analysed situation, it is the fixing system of metal sheets to the substructure that was responsible for visible damages. Once the metal sheets have folded, and bulges as well as wrinkles appeared, the material has to be replaced, because usually it cannot return to its original flat form. Due to a rigid fixing of such cladding, and lack of gaps between the sheets, that does not allow any thermal movement, it has come to permanent unanticipated irregular deformations of the facade surface. In order to improve the aesthetics of the facade, a replacement of the material is unavoidable; but this infringes the principle of dematerialization and entails an increase in recurring embodied energy of the building.

Case C2	
Building	Lunchroom Lent, Overschiestraat, Amsterdam, The Netherlands
Building component	Exterior finish
Material	Metal
Negative process	Irregular wrinkles and bulges of metal sheets
Negative consequences	Negative aesthetic appearance; Loosening of fixing screws and possible water penetration inside wall
Proposed alternative solution at design stage	Thicker metal sheet; Proper fixing of material allowing for metal sheet free movements and adequate gaps between sheets

Fig. 8. Permanent deformations of metal cladding. Restaurant pavilion. Amsterdam

Case C3. A similar situation with a faulty fixation system can take place even within building interiors. The stainless steel cladding of a round staircase at the commercial centre Old Brewery (Stary Browar) in Poznan has also been subjected to a comparable thermal disfigurement. Large-size panels had been riveted to a steel structure in a way impossible for them to extend or contract along with changing temperature. As a result of that faulty solution, permanent wrinkles and bulges appeared spoiling the previously elegant look of the silver cylinder (Fig. 9). A complete exchange of that expensive material, and the application of a more reliable technology, is the only method for restoring the original aesthetic values of this building component; but this option increases substantially the embodied energy content of the building in its life cycle. Interesting is an analysis of the causes of that unpredicted deformation. It occurred as a result of excessive exposure to heating and subsequent extension of the cladding, due to the location of a large long skylight directly above the staircase. This configuration caused the penetration of intensive solar radiation incident on the cladding material, which resulted in its extension and deformations.

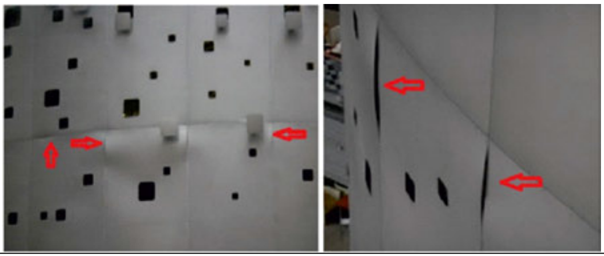
Case C3	
Building	Old Brewery (Stary Browar) Commercial Center, Poznań, Poland
Building component	Interior finish
Material	Metal
Negative process	Irregular wrinkles and bulges of metal sheets
Negative consequences	Negative aesthetic appearance; Loosening of screws and potentially protruding sheets
Proposed alternative solution at design stage	Suitable fixing method allowing for metal sheet free movements and adequate gaps between sheets; Sun shading system integrated with roof glazing

Fig. 9. Staircase with stainless steel cladding. Permanent deformations caused by a faulty fixation system. Commercial centre Old Brewery (Stary Browar), Poznan

6. Discussion

The analysed examples deliver a valuable information about some novel solutions, which still have an experimental character. Every building technology and material define a given embodied energy that can be quantified. However, the complex interrelations between materials, methods of their installation in buildings, vulnerability to potential mechanical and climatic damages exert a synergic impact, and make thereby the durability of building systems extremely difficult to assess; so, it is also their embodied energy, which appears to be hardly quantifiable. Due to serious complications in the precise and fully reliable calculations in many cases, this procedure seems to be impractical. This view comes to mind especially given the fact, that it is usually architects who take decisions as to the technology to be implemented. Unfortunately, they have as a rule neither a sufficient knowledge and expertise, nor are they particularly interested in these issues. Environmentally-oriented assessment and certificate systems currently offered are helpful, but in the every-day professional practice, in the majority of cases, their use is still not a habit, due to the "... inertia of the building professions and the construction industry" [20]. Gathering data for a life-cycle inventory (LCI) can be a time-consuming task, as many companies either view such data as confidential, or simply do not have the sort of detailed records needed for a credible whole-life study. The impact assessment and interpretation stages are still undergoing refinement [18]. "An important obstacle in this development is the lack of collective vision and guidance for future green buildings including design, components, systems and materials, which may affect the present rapid progress in this arena" [20]. In view of this, it seems that using some methods of simplified comparison accessible to non-experts in this area make sense, and could be satisfying at this stage of developments in the ecology-oriented building. Temporary methods of embodied energy assessment, helpful in making comparisons of technologies, can be considered useful and recommendable to make buildings greener. A promising tool in this approach can be the application of BIM technique, which permits to easier analyse the materials used in a construction, and to rapidly replace them in order to optimize their selection in terms of quantity and embodied energy. Integrated design method is another recommendable option for bringing dematerialization effects.

The experience and outcomes drawn from this research, as well other similar to be conducted, could allow to formulate a set of recommendations for construction stakeholders, and especially architects. As the examples in chapter 3 show, endeavours in experimental application of new technologies entailing relatively low initial embodied energy, may offer fully positive or sometimes only partly positive technical effects. But from the cases of faulty solutions appropriate conclusions can be drawn, and they would enhance the relevant building theories. In the cases B1, B2, B3, it is insufficiently analysed local climatic conditions prior to the designing stage, and some features of surroundings, as well as improper choice of materials that played their role. It should be mentioned that in the case B3 an advanced important rusting process should have been easily predicted, and therefore the case has not contributed to the enhancement of already well known knowledge. These cases prove that the problems of maintenance and related materials, and ways of their installation, are neglected. Recurring embodied energy of maintenance works can be reduced not only by way of dematerialization through the methods indicated for the cases B1, B2, B3, but also by permitting the exterior finish materials and components to further degrade and age up to the end point of technical performance, however, still remaining secure for the building's stability and its users. This would require far-reaching changes in conventional aesthetic views of the public, who should positively assess and accept the aesthetics of aged materials, as it occurs, for example, in the case of patina-covered copper finishes. So far, this change in the preference for classic aesthetics is dubious. Negative effects indicated in the C1, C2, C3 could have been anticipated, as they come not rarely. But as a surprise can be considered the case of the interior finish deformations (case C3). An analysis carried out at the site has indicated that their cause was an iterative solar radiation penetrating the interior through an abundantly glazed roof.

The research can be useful and help especially architects in their rough preliminary assessments of proposed technologies in view of their sustainable parameters, turning their attention to some unpredicted possible effects impacting initial and recurring embodied energy of proposed solutions to building components and details.

7. Conclusions

The issue of embodied energy in building materials and construction technologies, as an important part of sustainable architecture and construction, is a multi-faceted problem. Stakeholders in architecture and construction industry seem to see this issue of embodied energy in a somewhat narrowed perspective. The three analysed aspects of material input in buildings should be carefully considered in constructions. It is difficult to carry out a precise quantitative comparative analysis of different systems in this regard, because of various methods of calculations for embodied energy content in materials, and in complex building systems. Therefore, the method of deduction giving a rough estimate of embodied energy at the preliminary stage of design could be considered useful and recommended. A recommendable way of dealing with the problem can be the use of different databases for the optimum choice of suitable materials, indicated in some sources [7].

The accessible methods of rapid quantitative assessment of embodied energy in materials and building components are expected to be used in a much larger scale than they have been so far. But simpler and much faster deductive way seems to be reasonable and applicable in the case of some building components and details, like elevation technologies, finishing materials, fixing systems. This method requires also the inclusion of an in-depth study of local climatic factors, mutual configuration of building components, spatial surrounding elements and local vehicular traffic intensity. This set of impacting factors is, to my knowledge and experience, hardly ever taken into account at the design stage by architects and collaborating specialists. The research outcomes have been achieved on the basis of studies carried out on relatively few examples of buildings and their components, which may be considered relatively poorly documented. But despite that, they examine some model cases of approach to the analysed issue of embodied energy, which can indicate new ways for handling materials in buildings. Detailed scale of buildings is presumably not seen as embodied energy- related interesting issue at this stage of sustainability awareness. Future research should analyse more examples of non-conventional solutions giving better results of dematerialization in construction, due to the significance of this issue for the sustainability paradigm.

The enhancement of designers' awareness and knowledge in this regard, through the presentations of faulty solutions leading to the effects contrary to dematerialization guidelines, can be helpful and cause higher awareness of stakeholders in the building processes. It is highly probable, that they will also contribute to a higher quality of architectural designs and constructed buildings extending their life cycle and operational performance within the frames of sustainability. The relevant competence of architects and construction engineers could also be enhanced by way of the actions of professional organizations, like chambers of architects or civil engineers. Helpful are courses and publications of instructive articles for those professionals on a regular basis, as it is in the case of some domestic research institutions.

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Badanie potencjału dematerializacji w celu redukcji energii wbudowanej w cyklu życiowym budynków

Słowa kluczowe: trwałość budynków, technologie budowlane, technologie zrównoważone

Streszczenie:

Jednym z podstawowych wymogów paradygmatu architektury zrównoważonej jest stosowanie materiałów i technologii budowlanych charakteryzujących się niską ilością energii wbudowanej. W artykule przedstawiono problem racjonalnego projektowania uwzgledniającego niską energochłonność części budynków i ich detali na konkretnych przykładach badanych realizacji obiektów budowlanych. Aby podnieść stosowne kompetencje profesjonalistów i innych uczestników procesu budowlanego artykuł proponuje pewne metody podejścia do tych zagadnień oparte na analizie problemu w zakresie trzech kierunków postępowania w celu oceny poprawności rozwiązań w omawianym zakresie. Zmniejszenie ilości stosowanych materiałów, czyli tak zwana dematerializacja, stosowanie w budownictwie nisko energochłonnych materiałów, redukcja ilości zabiegów konserwacyjnych, mniejsza częstotliwość wymiany elementów i materiałów budowlanych w czasie eksploatacji budynków oraz ich wyższa trwałość – to działania, które prowadzą do uzyskania oczekiwanych wyników pod tym względem. W artykule przedstawiono niektóre przykłady odpowiadające takiemu podejściu do projektowania współczesnych obiektów wykorzystujące najnowsze technologie budowlane zgodne z wymogami budownictwa zrównoważonego. Wskazano także kilka niewłaściwych sposobów rozwiązań technologicznych przynoszących efekty przeciwne paradygmatowi dematerializacji.

Zagadnienie zostało ujęte w ramy trzech rozdziałów traktujących osobno każdy z trzech rozważanych aspektów kwestii redukcji energochłonności poprzez stosowanie zasady dematerializacji przy pomocy wyżej wymienionych metod. Jak wskazały przedstawione przykłady realizacji z kilku miejsc w Europie, takie działania przyczyniają się nie tylko do uzyskania pozytywnych efektów energetycznych ale również do podniesienia walorów technicznych i estetycznych budynków promując współczesne właściwe podejście do zagadnień budowlanych. Jednocześnie wspomniane negatywne przykłady wykazały nie tylko wzrost nakładów energetycznych i materiałowych ale także w rezultacie ujawnienie niekorzystnych cech estetycznych.

Jak wynika z przedstawionych przykładów, pozytywne oraz błędne rozwiązania można spotkać w różnych miejscach Europy, niezależnie od jakości miejscowej kultury budowlanej. Jako główne powody negatywnych rozwiązań należy uznać, jak się wydaje, brak odpowiedniej wiedzy wśród projektantów i wykonawców obiektów oraz brak prób wielostronnej analizy parametrów technicznych i energetycznych proponowanych technologii budowlanych w ramach holistycznego traktowania podejmowanych przedsięwzięć projektowych.

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