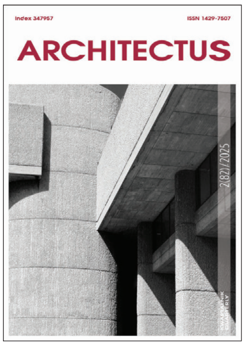

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Design strategies for achieving mono-material structures

Abstract

Increasing demands for the multi-aspect efficiency of buildings lead to the growing complexity of their partitions. This results in the subdivision of these partitions into increasingly specialized layers and, consequently, in the creation of complex multi-material systems – challenging to execute, requiring advanced expertise, significant financial input and resources, and often marked by higher failure rates and faster degradation. An alternative lies in mono-material systems – architectural assemblies homogeneous in terms of the material used in construction. Their implementation may contribute to increased sustainability and technological inclusiveness, as well as foster the development of new aesthetics, aligning with the values promoted by the New European Bauhaus initiative.

The study aimed to develop design strategies for creating mono-material partitions and, consequently, mono-material structures. The subject of the study focused on mono-material partitions identified in recently constructed European buildings, selected through a critical literature review. In an analysis based on case studies, desk research, and document examination, the base material of each partition was determined first. Then, the internal partition structures were identified by defining layer numbers, their types and functional roles within the partitions. Methods of using the base material that led to obtaining mono-materiality were also indicated. Finally, strategies for achieving mono-material structures were identified, systematized, and described using comparison and synthesis.

The article demonstrates that these strategies are defined through functional operations on partition layers, encompassing three main actions: layer unification, layer bonding, and layer multiplication. Implementing strategies requires a shift in the approach to material use, either appropriate usage, strengthening or inducting new properties of this material. Each strategy includes three approaches: one relates to modifying the internal structure of the base material, the second to shaping the base material and the third to accumulating unmodified base material. These strategies and approaches are universally applicable, not limited to specific materials.

Key words: mono-material structures, design strategies, layer unification, layer bonding, layer multiplication

Introduction

Increasing demands for building performance are leading to a growing complexity in building partitions. As a result, their internal composition becomes a system of successive, highly specialized layers (Moe 2014, 254). This process leads to developing complex and costly construction technologies that consume more resources and require advanced expertise (Binder, Riegler-Floors 2019, 102). Consequently, the risk of failure and the rate of degradation of the entire building increase (Brand 1995, 13).

As an alternative to these technologies, the article discusses mono-material systems – structures in which all building partitions and their layers are made from a common base material (Binder, Riegler-Floors 2019, 102), leading to a simplification and unification of their internal composition. This approach enables easier renovation and reuse of the entire building. Moreover, the reduced number of building elements allows for simpler disassembly and reuse of individual components. In the case of demolition, the recovered material is relatively homogeneous, which facilitates its reuse or disposal (Addis 2006, 13). The lower complexity of mono-material systems also reduces construction costs and simplifies the building process. This, in turn, may contribute to increased technological inclusiveness. Mono-material systems are therefore more accessible to less-qualified builders and lower-income users, while also promoting sustainability through a closed material cycle. These two features also give rise to a new architectural aesthetic. Altogether, they align with the values

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promoted by the New European Bauhaus (NEB) initiative, which addresses, among other issues, the role of materials in achieving its stated objectives (European Commission 2022, 8).

The assumption that building partitions originate from a single base material requires that this material exhibit structural, insulating, protective, and aesthetic properties. This necessitates exploring appropriate methods of using, enhancing, and modifying material properties, as well as inducing entirely new ones. Paola Antonelli described this process as the transmutation of materials – adapting a material to exhibit atypical, often mutually exclusive characteristics (Antonelli 1995, 15).

Based on the above, the research problem was formulated around two key questions:

1. Are there identifiable patterns of working with materials (strategies) within building partitions, the application of which may lead to the development of mono-material systems?

2. Are these patterns (strategies) directly related to specific materials, or are they independent and thus universally applicable to various materials?

The scope of the study covered building partitions with mono-material characteristics, identified in contemporary buildings constructed after the year 2000 across Europe. The objective was to analyze the internal composition of mono-material partitions and, based on this analysis, to develop patterns that enabled their realization. It was assumed that the study would confirm the hypothesis that it is possible to formulate strategies which, through appropriate approaches to the use of any given material, would allow for the creation of such partitions and, consequently, entire mono-material systems.

The article presents the analysis and results of the study, which led to the identification and systematization of these strategies. The analysis also confirmed their universal nature and the potential for application regardless of the type of base material.

State of research

In the available body of literature, most works focus on the potential of specific materials for the implementation of mono-material systems. Through the comparison of structural, thermal, diffusion, and acoustic properties of selected materials, Markus Binder and Petra Riegler-Floors developed system diagrams indicating the degree to which these can be realized in a mono-material manner. In their work *Mono-Material Construction*, they discussed monolithic single-layer systems and layered mono-material assemblies (Binder, Riegler-Floors 2019). In turn, Till Boettger and Ulrike Knauer equated mono-material systems with monolithic, single-layer partitions. They identified their low level of complexity as offering potential for reducing a building's environmental impact. They also emphasized their aesthetic value, referencing the modernist idea of "material honesty". These authors classified buildings with mono-material system characteristics according to the materials used in their construction (Boettger, Knauer 2023). A similar classification was adopted by Elina Koivisto, who, however, linked mono-material systems to the context of traditional building practices. Koivisto observed that promising new material solutions, introduced without adequate research, often degrade indoor conditions. As an alternative, she proposed traditional single-layer mono-material technologies (Koivisto 2021).

Furthermore, the literature includes studies focused on specific technologies with a mono-material character, such as the use of digital fabrication for shaping timber partitions (Bucklin et al. 2021), gradient modification of concrete properties within a partition (Torelli, Giménez Fernández and Lees 2020), rammed raw earth[1] construction (Kapfinger, Sauer 2015), the application of mycelium-based materials[2] as building components (Bitting et al. 2022), or the use of traditional log construction techniques (Lakkala, Luusua and Pihlajaniemi 2020).

A literature review reveals that it predominantly consists of isolated investigations into individual materials and technologies. The few cross-sectional publications aggregate examples of mono-material systems, organizing them by material type and comparing partition parameters. However, there is a noticeable absence of a systemic approach that would characterize universal patterns of working and general strategies applicable to mono-material systems. This gap in the current body of knowledge constitutes the primary rationale for this article and serves as the starting point for the research undertaken.

Analysis of selected mono-material systems – research description

Step 1. Selection of mono-material building objects

Fourteen building objects were selected for the study, each either entirely or partially constructed using technologies exhibiting mono-material characteristics. This group was supplemented by an additional technology of functionally graded concrete, currently in an experimental phase (Table 1, no. 1.3). This exception was made due to the unique internal structure of the hypothetical partition – its omission could have affected the study's outcome. Furthermore, the selection was guided by the criterion of recency – the year 2000 was adopted as the lower time boundary for implementation. A territorial criterion was also applied, limiting the selection to buildings constructed in Europe (in reference to the thematic connection with the NEB programme). One exception was made (Table 1, no. 6.1) – a prototype building made of mycelium bricks. Similar, smaller-scale structures have been built in Europe (Bitting et al. 2022, 13, 14), but it was deemed appropri-

[1] The term "raw earth" refers to the use of unfired earth for construction (Kelm 1996, 5) that is, a suitable mixture of mineral-origin particles of varying grain sizes extracted directly from the ground (Kelm, Długosz-Nowicka 2011, 66). Raw earth can be processed using various techniques, such as ramming, casting of liquid mixtures, or pressing (Kelm 1996, 20).

[2] Mycelium is the vegetative part of fungi, consisting of a dense network of hyphae capable of binding organic substrates and transforming them into composite materials with potentially broad applications, including in the construction industry (Bitting et al. 2022).

Table 1. Analysis of selected mono-material partitions: step 1 and step 2 (elaborrated by T. Broma based on: Schittich 2005; Binder, Riegler-Floors 2019; Torelli, Giménez Fernández and Lees 2020; Hugentobler et al. 2016; Avarrus Arkkitehdit 2024; Stieglmeier 2021; Lakkala, Luusua and Pihlajaniemi 2020; Bucklin et al. 2021; Boettger, Knauer 2023; Kapfinger, Sauer 2015; Bitting et al. 2022)
Tabela 1. Analiza wybranych przegród monomateriałowych: krok 1, krok 2 (oprac. T. Broma na podstawie: Schittich 2005; Binder, Riegler-Floors 2019; Torelli, Giménez Fernández i Lees 2020; Hugentobler et al. 2016; Avarrus Arkkitehdit 2024; Stieglmeier 2021; Lakkala, Luusua i Pihlajaniemi 2020; Bucklin et al. 2021; Boettger, Knauer 2023; Kapfinger, Sauer 2015; Bitting et al. 2022)

A	–	B	C	D	E	F
Base material	no.	Analyzed building structure author(s) location; completion date	Technology	Partition thickness [mm]	Number of layers	Layers from the outside – thickness [mm] (layer functions: a – aesthetic, p – protective, i – insulating, s – structural)
Concrete	1.1	Single-family house design: Patrick Gartmann Chur, Germany; 2003	monolithic concrete	450	1	1. Insulating concrete– 450 (a / p / i / s)
	1.2	Single-family house design: Adamiczka.Broma Wrocław, Poland; 2004	aerated concrete	395	3	1. Lime plaster – 15 (a / p) 2. Aerated concrete block – 365 (s / i) 3. Cement–lime plaster – 15 (p / a)
	1.3	not applicable (experimental technology)	functionally graded concrete	–	1	1. Gradient concrete – (–) (a / p / i / s)
Ceramics	2.1	2226 Office Building design: Baumschlager Eberle Lustenau, Austria; 2013	porous ceramic blocks	760	4	1. Cement–lime plaster and lime skim coat – 20 (e / p) 2. Insulating block – 365 (i / s) (vertical joint – 20) 3. Structural block – 365 (i / s) 4. Cement–lime plaster and lime skim coat – 20 (e / p)
	2.2	Helsingin Muurarimestari Apartment Building design: AVARRUS Helsinki, Finland; 2024	solid brick	720	4	1. Hollow solid brick – 135 (a / p) (vertical joint – 45) 2. Hollow solid brick (3 layers) – 585 (a / p / i / s)
Timber	3.1	Bürohaus Küng Office Building design: Seiler Linhart Alpnach, Switzerland; 2024	cross-laminated timber (CLT)	420	14 (2×7)	1. 7-layer CLT panel – 210 (a / p / i / s) 2. 7-layer CLT panel – 210 (a / p / i / s)
	3.2	School Campus design: Lukkaroinen Pudasjärvi, Finland; 2016	log construction timber	275	1	1. Timber log – 275 (a / p / i / s)
	3.3	IBA Timber Prototype House design: ICD University of Stuttgart Stuttgart, Germany; 2019	milled solid timber	445	3	1. Timber boards 20 (a / p) (ventilation gap – 45) 2. Waterproof membrane (p) 3. Timber profile with a variable cross-section – 400 (a / p / i / s)
	3.4	Private Recreation Building design: Adamiczka.Broma Jeziorna, Poland; 2023	timber frame	350	6	1. Timber boards – 20 (a / p) (ventilation gap / battens and counter-battens – 90) 2. Tongue-and-groove wood wool board – 60 (i) 3. Timber studs and wood fiber insulation – 160 (i / s) 4. OSB-3 board – 15 (p) 5. Timber boards – 15 (a)
Stone	4.1	1413 Single-Family House design: HARQUITECTES Ullastret, Spain; 2017	jointed stone	650	1	1. Stone blocks bonded with glass-exposed mortar – 650 (a / p / i / s)
Raw earth	5.1	Rauch House design: Roger Boltshauser and Martin Rauch Schlins, Austria; 2008	rammed earth	590	3	1. Raw earth – 450 (a / p / i / s) 2. Reed mat – 100 (i) 3. Clay base coat and plaster – 40 (a / p)
	5.2	Le Cap Business Incubator design: Hors les Murs and Reach & Scharff Saint-Clair-de-Tour, France; 2018	poured earth	520	3	1. Poured earth – 300 (a / p / i / s) 2. Wood wool – 200 (i) 3. Clay plaster – 20 (a / p)
	5.3	Casa de Tapia design: Edra arquitectura km0 Ayerbe, Spain; 2014	light clay	450	3	1. Lime plaster – unevenness filler (a / p) 2. Light clay – 450 (a / p / i / s) 3. Lime plaster – unevenness filler (a / p)
Alternative materials	6.1	Hy-Fi Pavilion (prototype) design: The Living New York, USA; 2014	mycelium bricks	225	1	1. Mycelium brick – 225 (a / p / i / s)
	6.2	Cork House design: Dido Milne, Matthew B. Howland, Oliver Wilton Berkshire, United Kingdom; 2019	cork blocks	500	1	1. Cork block – 500 (a / p / i / s)

ate to include this alternative material in the analysis due to its potential for realising full-scale structures. The final selection criterion was material diversity, which allows verification of the hypothesis that the strategies leading to mono-material systems are not tied to any specific material. The selected buildings are listed in Table 1, col. B.

Prior to conducting the core analysis, it was assumed that the study would focus on segments of mono-material structural systems – specifically, external vertical building partitions. This simplification served to standardize the elements being compared, enabling direct juxtaposition. Notably, the research aims to abstract recurring patterns in achieving mono-material systems rather than to prove the feasibility of constructing such systems using a particular material. Consequently, excluding other types of partitions does not affect the outcome of the analysis.

Step 2. Characteristics of the selected mono-material partitions

The selected group of partitions exhibiting mono-material characteristics was analysed using case study methodology, desk research, and document analysis. The study was based on architectural documentation, authors' descriptions, and publications concerning the selected buildings. The collected information was presented in a standardized format in Table 1. The partitions were categorized by base material[3], distinguishing concrete, ceramics, wood, stone, raw earth, and a group of alternative materials (Table 1, col. A). Subsequently, the technologies used to construct the individual mono-material partitions were identified (Table 1, col. C). The table also includes data on the thickness of the partitions, the number and types of layers they consist of, and the thickness of each layer (Table 1, cols. D, E, and F).

Step 3. Functional analysis of the selected mono-material partitions

The collected data regarding the layers of the building partitions were examined from a functional perspective. The following division of layer functions was adopted:

1) structural (s) – the ability to bear and transfer loads (Pyrak, Włodarczyk and Woliński 2008, 173),

2) insulating (i) – regulating the conditions on one side of the partition by reducing the impact of those present on the other side (Moe 2014, 13),

3) protective (p) – shielding the partition from degrading chemical, physical, and biological factors (Ściślewski 2018, 830, 831),

4) aesthetic (a) – the perception of the partition by users (Böhme 2017, 59–62).

[3] The term base material should be understood as encompassing both: (1) a raw material, that is, an unprocessed substance obtained through agriculture, forestry, mining, or waste processing industries and transformed into goods through manufacturing processes (Black, Kosher 2011, 10) (e.g., wood); and (2) a starting material, meaning a substance already processed from a raw material and prepared for further transformation (e.g., ceramics, concrete).

Each layer was assigned one to four of the listed functions, depending on its role within the partition. Diagrams were also developed to visually represent the distribution of these functions across the layers, as shown in Figure 1. This functional approach to mono-material partitions aimed to uncover relationships between functions – revealing their overlaps, partial intersections, duplications, or complete separations. The standardized diagrams further enabled comparative analysis between the partitions and the identification of patterns that lead to the formation of mono-material systems.

Step 4. Identification of strategies and approaches in the pursuit of mono-materiality in selected partitions

Using synthesis and comparison, the functional operations performed on the layers of each partition that led to the realization of mono-material partitions were identified (Table 2, col. G). These operations were then linked to specific actions that modified the base material's properties (Table 2, col. H). The actions were classified into three approaches: modifying the internal configuration of the base material, shaping the base material, and accumulating the base material. Subsequently, through synthesis, these data were used to derive, systematize, and describe the strategies aimed at achieving mono-material building systems.

Results

The results of the analysis are presented in Table 3, which provides a complete summary of the strategies aimed at achieving mono-material systems and the methods of implementing these strategies. The table also outlines the objectives of each strategy and the means of their realization. The strategies were derived based on operations performed on the layers, which lead to a redistribution of functions within the building partition. The following three strategies were identified:

I. Unification of layers.
II. Merging of layers.
III. Multiplication of layers.

The strategies are implemented through a shift in the approach to the base material, allowing for the use of its original properties, as well as their enhancement or the induction of new ones. These approaches are not determined by the strategies – they function independently. Three such approaches can be distinguished:

1. Modifying the internal configuration of the base material as a result of changes in its extraction or processing methods, or through the use of additives.

2. Shaping the base material appropriately within the components of individual layers or entire layers.

3. Accumulating the unmodified base material as a means of increasing the thickness of the layers.

It was also observed that analogous strategies and approaches to their implementation were applied to different materials. Therefore, it can be concluded that the base material does not directly determine both the strategies and the approaches – they possess a universal character in the con-

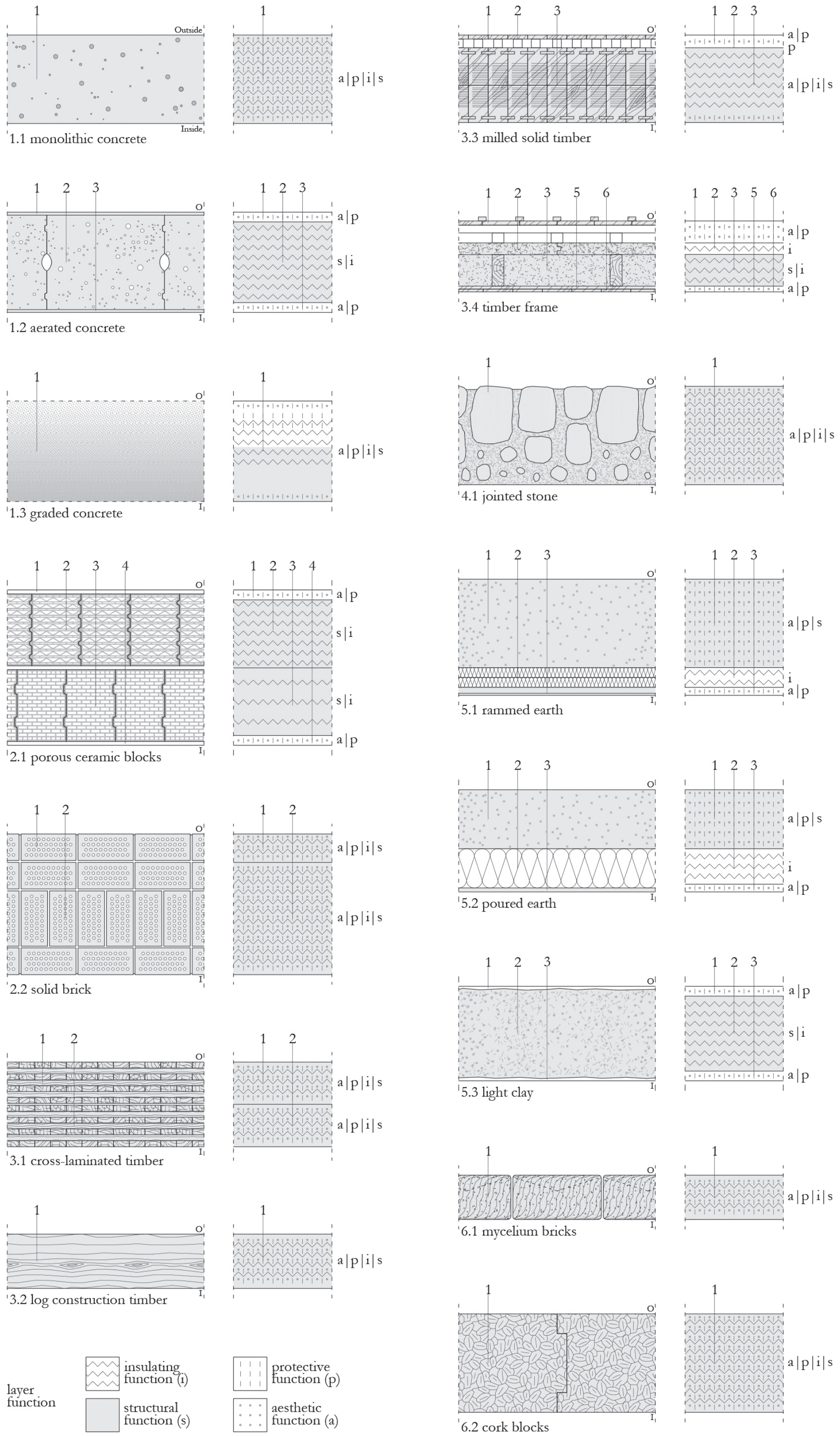


Fig. 1. Analysis of selected mono-material partitions: step 3 – horizontal sections of analysed mono-material partitions and their functional diagrams (elaborated by T. Broma based on: Schittich 2005; Binder, Riegler-Floors 2019; Torelli, Giménez Fernández and Lees 2020; Hugentobler et al. 2016; Arkkitehdit 2024; Stieglmeier 2021; Lakkala, Luusua and Pihlajaniemi 2020; Bucklin et al. 2021; Boettger, Knauer 2023; Kapfinger, Sauer 2015; Bitting et al. 2022)

Il. 1. Analiza wybranych przegród monomateriałowych: krok 3 – przekroje poziome analizowanych przegród monomateriałowych i ich diagramy funkcjonalne (oprac. T. Broma na podstawie: Schittich 2005; Binder, Riegler-Floors 2019; Torelli, Giménez Fernández i Lees 2020; Hugentobler et al. 2016; Arkkitehdit 2024; Stieglmeier 2021; Lakkala, Luusua i Pihlajaniemi 2020; Bucklin et al. 2021; Boettger, Knauer 2023; Kapfinger, Sauer 2015; Bitting et al. 2022)

text of the mono-material system concept. Moreover, as confirmed in the analysed partitions, in pursuing a mono-material system, the strategies and approaches may be applied individually and singularly, or repeatedly and in combination. The following sections describe each strategy in greater detail, along with the three accompanying approaches. For each, an example of a relevant partition is provided.

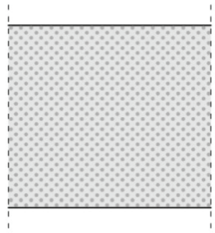
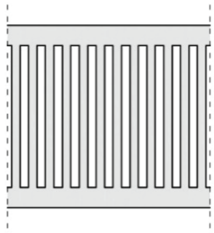
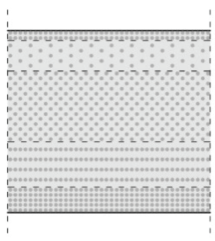
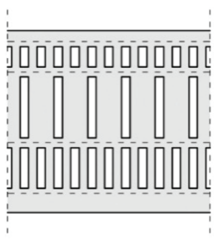
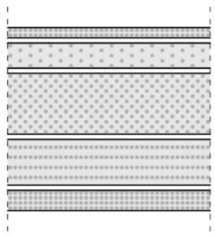
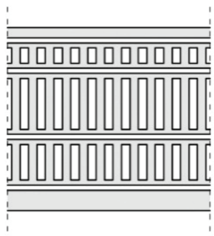
I. The unification of layers strategy

The layer unification strategy entails the homogenization of layers, ultimately aiming to reduce the total number of layers within the partition. The final objective of implementing this strategy is to achieve a partition composed of

Table 2. Analysis of selected mono-material partitions: step 4 (elaborated by T. Broma)
Tabela 2. Analiza wybranych przegród monomateriałowych: krok 4 (oprac. T. Broma)

	G	H
No.	Applied strategy	Approach to implementing the strategy
1.1	(I) Unification of Layers: structural, insulating, protective, and aesthetic functions fulfilled by a single homogeneous layer	Approach 1 Modifying the internal configuration of the base material within the layer: use of an additive in the base material (expanded clay and expanded glass)
1.2	(I) Unification of Layers: structural and insulating functions fulfilled by a single homogeneous layer	Approach 1 Modifying the internal configuration of the base material within the layer: adding porosity to the base material (foaming agent)
1.3	(II) Merging of Layers: structural, insulating, protective, and aesthetic functions fulfilled by inseparable segments of a single heterogeneous layer	Approach 1 Local modification of the internal configuration of the base material within the layer: creating a gradient internal configuration of the base material
2.1	(I) Unification of Layers and (III) Multiplication of Layers: structural and insulating functions jointly fulfilled by two heterogeneous layers	Approach 1 Modifying the internal configuration of the base material within the layer: altering the internal structure of the base material (adding porosity) Approach 2 Shaping the base material within the layer: introducing air voids into the form of the base material Approach 2 Variable shaping of the base material for different layers: use of two differently formed layers made from the base material
2.2	(III) Multiplication of Layers: structural, insulating, protective, and aesthetic functions fulfilled by two homogeneous layers	Approach 3 Accumulating the base material by duplicating repeatable layers: use of four layers made from the base material
3.1	(II) Merging of Layers and (III) Multiplication of Layers: structural, insulating, protective, and aesthetic functions fulfilled by fourteen homogeneous layers	Approach 3 Accumulating the base material by duplicating repeatable zones within the layer: use of layers made from cross-laminated base material Approach 2 Accumulating the base material by duplicating repeatable layers: duplication of two layers made from the base material
3.2	(I) Unification of Layers: structural, insulating, protective, and aesthetic functions fulfilled by a single homogeneous layer	Approach 3 Accumulating the base material within the layer (increased thickness): applying increased thickness of the base material
3.3	(II) Merging of Layers: structural, insulating, and aesthetic functions fulfilled by distinguishable segments of a single heterogeneous layer	Approach 2 Local variable shaping of the base material within the layer: introducing zones with different shapes into the base material
3.4	(III) Multiplication of Layers: structural, insulating, protective, and aesthetic functions fulfilled by separate layers	Approach 2 Modifying the internal configuration of the base material differently for each layer: use of differently processed base material to perform specialized functions within individual layers
4.1	(I) Unification of Layers: structural, insulating, protective, and aesthetic functions fulfilled by a single heterogeneous layer	Approach 3 Accumulating the base material within the layer (increased thickness): applying increased thickness of the base material bonded with mortar containing expanded glass
5.1	(I) Unification of Layers: structural, insulating, protective, and aesthetic functions fulfilled by a single homogeneous layer	Approach 3 Accumulating the base material within the layer (increased thickness): applying increased thickness of the base material
5.2	(I) Unification of Layers: structural, insulating, protective, and aesthetic functions fulfilled by a single homogeneous layer	Approach 3 Accumulating the base material within the layer (increased thickness): applying increased thickness of the base material
5.3	(I) Unification of Layers: structural, insulating, protective, and aesthetic functions fulfilled by a single homogeneous layer	Approach 1 Modifying the internal configuration of the base material within the layer: use of an additive in the base material (straw)
6.1	(I) Unification of Layers: structural, insulating, protective, and aesthetic functions fulfilled by a single homogeneous layer	Approach 1 Modifying the internal configuration of the base material within the layer: use of a specific harvesting process of the base material (form-filling through growth to desired density)
6.2	(I) Unification of Layers: structural, insulating, protective, and aesthetic functions fulfilled by a single homogeneous layer	Approach 1 Modifying the internal configuration of the base material within the layer: use of a specific processing method for the base material (expansion)

Table 3. Design strategies and approaches for achieving mono-material structures (elaborated by T. Broma)
Tabela 3. Strategie i sposoby podejścia w dążeniu do osiągnięcia monomateriałowych ustrojów (oprac. T. Broma)

	1. Approach to implementing the strategy modifying the internal configuration of the base material	2. Approach to implementing the strategy shaping the base material	3. Approach to implementing the strategy accumulating the unmodified base material
(I) Unification of Layers Strategy unifying the structure of the mono-material partition by reducing the number of layers			
strategy objective: a single multifunctional mono-material layer with a homogeneous structure, simultaneously fulfilling all partition functions	method of achieving the objective in approach 1: modifying the internal configuration of the base material within the layer	method of achieving the objective in approach 2: shaping the base material within the layer	method of achieving the objective in approach 3: accumulating the base material within the layer (increasing thickness)
(II) Merging of Layers Strategy differentiating distinguishable but inseparable zones within the mono-material partition through the permanent merging of layers			
strategy objective: a single multifunctional mono-material layer with specialized zones, collectively fulfilling all partition functions	method of achieving the objective in approach 1: locally modifying the internal configuration of the base material within the layer	method of achieving the objective in approach 2: locally varying the shaping of the base material within the layer	method of achieving the objective in approach 3: accumulating the base material by replicating repetitive zones within the layer
(III) Multiplication of Layers Strategy applying a sequence of separable layers that together form a mono-material partition			
strategy objective: a mono-material sequence of single- or multifunctional layers, collectively fulfilling all partition functions	method of achieving the objective in approach 1: modifying the internal configuration of the base material differently for individual layers	method of achieving the objective in approach 2: differentiated shaping of the base material for individual layers	method of achieving the objective in approach 3: accumulating the base material by replicating repetitive layers

a single layer that fulfills all required functions. A defining feature of such a layer is its homogeneous internal structure – its entire cross-section is uniform, with no distinguishable zones. As previously stated, this strategy may be implemented through one of three approaches:

1. Modification of the internal configuration of the base material in the context of unification occurs uniformly within a single layer, allowing it to perform all the necessary functions of the partition. Modern building materials are often complex, multi-component systems (Stefańczyk, Lipczyńska 2005, 12). Therefore, an example of this approach involves altering the proportion of material components, substituting them with other substances, or incorporating additives that permanently change their properties. A representative example is the house in Chur (Switzerland) by Patrick Gartmann (Table 1, no. 1.1). There, a reduction in the number of layers was achieved by modifying the concrete mix – gravel was replaced with expanded clay, and sand with expanded glass. This enabled a monolithic, single-layer concrete shell to fulfill all

partition functions without additional insulation[4] (Schittich 2005, 146–151).

2. An example of the second approach – shaping the base material within a layer to expand its functional properties – can be found in ceramic blocks[5]. These blocks are formed as a series of thin-walled surfaces enclosing chambers filled with air voids (Małasiewicz 2005, 181–183). This design significantly improves thermal insulation, and together with the material's inherent properties, enables the unification of structural and insulating functions within a single layer (Table 1, no. 2.1).

3. In the context of unification, accumulating the base material within a single layer increases its thickness. In this way, the material's original properties – enhanced through the expanded cross-section – become sufficient to fulfill all required functions. The school campus in Pudasjärvi (Finland), completed in 2016 by Lukkaroinen Architects, exemplifies this approach (Table 1, no. 3.2). Traditional log construction was used, with a single wooden layer of appropriate thickness fulfilling structural, insulating, and aesthetic roles (Lakkala, Luusua and Pihlajaniemi 2020).

II. The merging of layers strategy

The merging of layers involves the creation of distinguishable but inseparable zones within a mono-material partition, resulting from the permanent joining of layers. Ultimately, this strategy leads to a single mono-material multifunctional layer composed of specialized zones that collectively fulfill all required functions. In contrast to the unification strategy, the resulting layer is characterized by a heterogeneous internal structure. The merging strategy can be implemented in three ways:

1. The first involves locally modifying the internal configuration of the base material within the layer. An example is a gradient-based layer (Table 1, no. 1.3), in which zones with varying material properties fulfil different functions. This variability occurs continuously across the cross-section – no clearly homogeneous segments exist. An experimental technology that allows for such internal composition is functionally graded concrete. The variation in properties is achieved by dynamically adjusting mixture proportions during spraying with nozzles or by layered application with printheads. Alternatively, a gradient profile can be obtained through controlled segregation of components under gravity or centrifugal force[6] (Torelli, Giménez Fernández and Lees 2020, 10, 11).

2. The second method involves locally differentiated shaping of the base material within the layer. This approach was applied in constructing the IBA Timber Prototype House (Table 1, no. 3.3), developed by ICD at the University of Stuttgart. The partitions of the pavilion were made from solid, notched spruce beams joined with wooden dowels and interlocks. The horizontal cross-section of the beams is divided into three functional zones: a densely notched insulating zone, an uncut structural zone, and a closing/sealing zone with assembly notches[7] (Bucklin et al. 2021, 7, 8). This system incorporates inseparable yet clearly distinguishable and functionally specialized zones within a single layer.

3. The third approach involves the accumulation of base material through the repetition of inseparable zones with specialized functions. This approach is exemplified by cross-laminated timber (CLT) panels used, for instance, in the construction of the office building in Alpnach, Switzerland, designed by Seiler Linhart Architekten (Table 1, no. 3.1). The visible outer layers of the panels were made from high-quality timber serving an aesthetic function. In contrast, inner layers were composed of waste wood whose irregularities created thin internal air pockets, enhancing the thermal insulation of the partition. At the same time, all layers collectively perform the structural function (Stieglmeier 2021, 34–38).

III. The multiplication of layers strategy

The layer multiplication strategy involves using a sequence of separable layers that together form a mono-material partition. These layers can be individually distinguished, and each may serve a specialized function or be multifunctional. The goal is to achieve mono-materiality by ensuring all layers originate from the same base material. This strategy can be implemented through three approaches:

1. The first approach involves modifying the internal configuration of the base material differently for each layer. This allows them to serve specialized functions within the partition. An example is the technology of prefabricated timber frame panels used in the summer house in Jeziorna, designed by Adamiczka.Broma Studio (Poland) (Table 1, no. 3.4). Its structure comprises a wooden frame reinforced internally with OSB-3 boards that also function as a vapour barrier. Wood fibre insulation was placed between the frame elements, while external wood wool panels reduce thermal bridging and ensure windproofing. The assembly is covered with boards mounted on a wooden batten system.

2. The second approach relies on shaping the base material differently across layers. This was applied in the construction of the 2226 office building in Lustenau (Austria) by Baumschlager Eberle Architekten (Table 1, no. 2.1). The external walls consist of two layers of perforated ceramic blocks, each with distinct shaping. The outer layer is formed to enhance thermal insulation at the expense of structural capacity, while the inner layer comprises blocks

[4] An exception is the roof, which is covered with a permanently flexible cementitious mortar.

[5] Porous ceramic blocks are also an example of the first approach. During firing, combustible additives mixed with the clay oxidize, leaving behind pores. The altered internal structure of the base material improves its thermal performance.

[6] This technology is currently being developed as an attempt to improve the strength and performance of concrete elements; however, it also holds significant potential for achieving mono-material structural systems.

[7] The structure was additionally complemented with external membranes providing waterproofing.

with increased load-bearing capacity. These two differently shaped layers from the same base material result in a mono-material partition with low thermal transmittance, high thermal mass, and appropriate strength parameters[8] (Hugentobler et al. 2016). This partition also exemplifies the simultaneous use of two different strategies (unification and multiplication) and three distinct approaches, demonstrating that their combined application is possible and that achieving a mono-material partition may require complex combinations of strategies and approaches.

3. The third approach involves the accumulation of the base material through the repetition of separable layers. An example is the previously discussed office building in Alpnach (Table 1, no. 3.1). To achieve complete mono-materiality, the previously described CLT wood panels were duplicated and joined with wooden dowels. The repetition of separable layers made from the base material enabled the fulfilment of all functions, thus resulting in a mono-material partition.

Conclusions

Based on the conducted analysis and its findings, the following conclusions were drawn:

1. It is possible to identify strategies whose implementation enables the discovery of the potential of a given base material for the realization of mono-material structural systems. These strategies refer to the operations of unification, merging, and multiplication performed – functionally – on the layers of a partition.

2. Implementing these strategies involves a shift in the approach to the base material, resulting in the use of its original properties, as well as their enhancement or the induction of new ones. Within each strategy, three approaches were distinguished: the first involves modifying the internal configuration of the base material; the second involves shaping the base material; and the third – accumulating the unchanged base material.

3. The strategies and corresponding approaches are universal and do not directly depend on specific materials. The recurrence of similar strategies and approaches in relation to various base materials confirms this.

4. To achieve mono-material partitions and, consequently, complete mono-material structural systems, the strategies and approaches may be applied individually and once, but also repeatedly and in combination.

[8] The construction of the external partitions, combined with gravity ventilation, enables the maintenance of interior temperatures within the range of 22–26°C without the use of heating, air conditioning, or mechanical ventilation. This is also the origin of the building's name.

Summary

This article presents a new perspective on the topic of mono-material structural systems. Based on case analysis, it identifies three universal strategies that potentially lead to the realization of mono-material systems: the unification of partition layers, the merging of layers, and the multiplication of layers. The effectiveness of these strategies depends on the appropriate use, enhancement, or induction of new properties in the base material, which may result from modifying its internal configuration, shaping it, or accumulating it in an unchanged form. These strategies are universal (independent of the material or partition type), offering a comprehensive and structured framework previously lacking in the literature. They simultaneously constitute a typology of mono-material partition technologies based on operations performed on layers. Moreover, the strategies and related approaches serve as tools for exploring the potential of realizing mono-material systems with a given base material. They can, therefore, be applied in the design process, adding practical value.

At the same time, a practical limitation in implementing the strategies was observed. Not all analyzed partitions – or the structural systems they belong to – were entirely mono-material. This suggests that achieving complete mono-materiality may be either unfeasible or unjustified due to cost or technological challenges. Notably, mono-material partitions pose specific challenges in harsher climatic zones, where temperature fluctuations, humidity variation, and overall environmental exposure make it difficult for a single layer to perform all necessary functions (especially within the unification strategy)[9].

Nevertheless, the inability to achieve full mono-materiality does not undermine the value of striving towards the highest possible degree of it. This underscores the need for further research to refine the definition of mono-material structural systems, including a clear indication of the minimum level and scope of base material usage. Future studies should also establish conditions under which supplementary materials may be used, as well as guidelines on their types. Addressing these research goals will improve the feasibility of mono-material structural systems and support the practical application of the proposed strategies.

[9] The implementation of mono-material structural systems in harsher climatic zones is not, however, impossible. This is evidenced by the deliberately selected examples from regions with such conditions. Most of them originate from Austria, Switzerland, Germany, Finland, the United Kingdom, and Poland.

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Streszczenie

Strategie projektowe służące osiągnięciu monomateriałowych ustrojów

Rosnące wymagania wobec wieloaspektowej efektywności budynków skutkują wzrostem poziomu skomplikowania ich przegród. Prowadzi to do rozszczepiania się tych przegród na kolejne wyspecjalizowane warstwy, a w konsekwencji do powstawania złożonych ustrojów wielomateriałowych – skomplikowanych wykonawczo, wymagających zaawansowanej wiedzy oraz dużych nakładów finansowych i zasobów, ale także cechujących się wzrostem poziomu awaryjności i szybszą degradacją. Alternatywą są ustroje monomateriałowe – heterogeniczne pod względem materiału wykorzystanego do wzniesienia budynku. Ich stosowanie może przyczynić się do wzrostu poziomu zrównoważenia i inkluzywności technologicznej, a także do wypracowania nowej estetyki, co wpisuje się w wartości promowane w projekcie Nowego Europejskiego Bauhausu.

Celem autora było wyprowadzenie strategii projektowych, których zastosowanie pozwala osiągnąć przegrody, a w rezultacie także ustroje monomateriałowe. Badaniem objęto przegrody o cechach monomateriałowych, które zidentyfikowano we współcześnie zrealizowanych budynkach na obszarze Europy. Ich wyboru dokonano na podstawie przeglądu literatury przedmiotu. Następnie w analizie opartej na studium przypadku, desk research i badaniu dokumentów określono zastosowane materiały bazowe i zidentyfikowano wewnętrzną budowę przegród poprzez wyznaczenie liczby warstw i wskazanie pełnionych przez warstwy funkcji. Wskazano także sposoby wykorzystania materiału bazowego, które doprowadziły do uzyskania przegród o cechach monomateriałowych. Następnie przez porównanie i syntezę, zidentyfikowano, usystematyzowano i opisano strategie w dążeniu do osiągnięcia ustrojów o charakterze monomateriałowym.

W artykule wykazano, że strategie te definiowane są poprzez operacje dokonywane w ujęciu funkcjonalnym na warstwach przegrody. Obejmują one trzy typy działań: unifikację warstw, spajanie warstw i zwielokrotnianie warstw. Wiąże się to bezpośrednio ze zmianą sposobu podejścia do materiału, czego efektem jest odpowiednie jego wykorzystanie, wzmocnienie lub wzbudzenie nowych właściwości tego materiału. W ramach każdej ze strategii wyróżniono trzy takie sposoby podejścia. Pierwszy związany jest z modyfikowaniem wewnętrznej konfiguracji materiału bazowego, drugi – z kształtowaniem materiału bazowego, a trzeci – z nagromadzeniem niezmienionego materiału bazowego.

Słowa kluczowe: ustroje monomateriałowe, strategie projektowe, unifikacja warstw, spajanie warstw, zwielokrotnianie warstw