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THE REUSE OF CERAMIC MATERIALS IN ARCHITECTURAL DESIGN – CASE STUDIES

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Abstract

The global construction industry, notorious for resource consumption and waste production, has found an interest in the circular economy and sustainable development practices. This paper examines the reusability of ceramic building materials within architectural designs, emphasizing the principles of the circular economy and the 3R concept with a special focus on reuse. By performing a comparative analysis of 26 buildings the research explores the strategies for reusing ceramic materials. It categorizes reuse into two approaches: re-creation and transformation, while also considering the prevention of materials from becoming waste. The analysis scrutinizes the origin and function of materials, their placement in new designs, and the reasons behind their reuse. The study delineates recurring design patterns of using reclaimed building materials. It also categorizes three main approaches to incorporating reused elements into new structures.

Keywords: **Reuse; Building materials; Circular economy; Construction and demolition waste; Ceramics.**

1. INTRODUCTION

Due to the negative environmental effects associated with the processes of manufacturing building materials and shrinking stocks of raw materials, the circular economy concept has gained a lot of interest in recent years [1–3]. Sustainable development approaches are also visible in legislation e.g. the European Union documents describe circularity as an essential strategy for sustainable development, low carbon emissions, and also a resource-efficient and competitive economy [4].

The building sector is responsible not only for growing resource consumption but also for generating a huge amount of waste. According to Eurostat data from 2020 construction and demolition waste constitute 37,5% of the European Union waste stream [5] and around 30-40% of all global waste production [6]. Every new building has the potential to become a material bank in the future, and the rise in building activity in recent years has made it more important than ever to create a plan for waste reduction and improved management of building materials [7]. Recently many attempts have been made to introduce a circular economy into the world of architectural design, from adaptive reuse, design for disassembly or deconstruction, and design for reuse to design for manufacture and assembly [1,8]. All of them are focusing on reducing the amount of waste produced by the building sector while following the 3R principle of reduce, reuse, and recycle which is one of the basics of the circular economy [9]. One of the best ways to lower waste generation and improve reuse practices is to design for waste prevention. It is especially important since the design stage is one of the most essential ones during the construction process and construction waste can originate as a result of poor design [10]. As the design plays a significant role as an element that can affect waste production in building projects special attention should be paid to the design process management [11, 12].

While many designing approaches are focusing on novel techniques to construct with the use of high quality, new, and more sustainable materials (thus fulfilling the postulate to reduce the amount of waste), most of the currently existing buildings were not designed with the thought of future reuse or dismantling. They will eventually become waste at the end of their lifecycles. However, instead of wasting those materials, they can be successfully incorporated into the design of new objects. Although it can be done in many ways, in this paper the emphasis was placed on reusing building materials. The reuse of architectural elements fits in with the waste management hierarchy developed by the European Commission and is considered a technique superior to recycling. Therefore, if possible, it should be chosen instead of recycling [13].

This research aims to analyze ways of reusing ceramic building materials. Research is based on selected sites and is focused on the relationship between the original and final place of materials implementation. Out of all of the materials, ceramic was chosen for this analysis since it is one of the most commonly used materials in the construction sector and has a high reuse potential [6, 14]. Moreover, reuse (apart from many environmental benefits like reducing raw material consumption or CO_2 emission) also offers advantages when it comes to energy demand. It is especially important in case of waste from kiln industries – so the one responsible for ceramic materials production - where highly endothermic decomposition reactions have already taken place [14]. Energy once used in the production of those products is recoverd when elements are being reused.

As many other works prove, it is possible to reuse pure ceramic materials like bricks or tiles as an aggregate for production of a new concrete [15–17] and mortar [18, 19]. Crushed bricks or tile can also be used as unbound aggregates for road construction [20]. However, in this article the emphasis was placed on more direct reuse in new building constructions, where it is still possible to see and recognize the initial element.

2. METHODOLOGY

A comparative analysis was performed to investigate what are the design approaches used, in terms of ceramic building materials reuse. 26 buildings were selected, first of all based on whether reclaimed ceramic building materials were used during their construction. In terms of preliminary criteria, the selection of examined objects was limited to cubature objects – urban designs, small architecture or artistic activities were not taken into account. The focus was placed only on facilities already completed and built after 2000 (projects that were only in the conceptual phase were not analyzed), with no restrictions on size, function, or location. Another important criteri-

Table 1.
Projects selected for comparative analysis (source: author's elaboration)

No.	PROJECT NAME	ARCHITECT
01	Cubo House	Phooey Architects
02	Ningbo Historic Musem	Wang Shu
03	Capilla San Bernardo	Nicolas Campodonico
04	Kamikatz Public House	Hiroshi Nakamura & NAP
05	Collage House	S+PS Architects
06	The Beehive	Luigi Rosselli + Raffaello Rosselli
07	China Academy of Arts' Folk Art Museum	Kengo Kuma & Associates
08	Upcycle House	Lendager Group
09	Pavilion 4	HMA Architects & Designers
10	Holiday Cabin	Lendager Group
11	Ravensburg Art Museum	LRO Lederer Ragnarsdóttir Oei
12	Resources Rows	Lendager Group
13	House for the Homeless	xystudio
14	Tongjiang Recycled Brick School	Joshua Bolchover - John Lin
15	Clay Roof House	DRTAN LM Architect
16	8B Nave	Arturo Franco
17	Kancelaria Adwokacka	Konior Studio
18	The Brick House	Betweenlines
19	Lisbjerg	Lendager Group
20	Kinglake Fire Proof House	Joost Bakker
21	Hill End Eco-House	Riddel Architecture
22	Pointe Valaine Community Centre	Smith Vigeant Architects
23	The City Houses	Vandkunsten Architects
24	VERBIEST	AgwA
25	Couronne 311	VLA Architecture
26	Chiro Itterbeek	Rotor

on was that all of them are well described in the literature, to make sure that all the information is verified. This is particularly important due to the location of buildings on several continents and the inability to conduct in situ tests. Moreover, thanks to criterion mentioned before, objects that have gained recognition in the field of architecture, including the material solutions used, were analyzed. The comparative study was based on the analysis of available literature, including data provided by individual designers and the analysis of available photos, videos and Google Street View images. The complete list of selected projects along with the architects of each of them is listed in Table 1. Project numbers assigned in the table will be used to identify objects throughout the rest of the paper.

Buildings were being compared to find answers to the following questions: what type of ceramic materials were used, what was their source, what was the original and final function, how were they used (design strategy), what was the place of their implementation, in what way were they incorporated into the new design and what was the reason for architects and investors to decide using reclaimed building materials.

Data was gathered according to the prepared checklist as shown in Table 2. First included information refers to the location of each project across 5 continents. Then, building's function is specified alongside the floor area. Next g column refers to the source of material. There are many different ways to obtain used materials and, in this paper, 5 sources were specified:

1. Demolition – every material that was obtained during the process of demolition or dismantling of existing building.
2. Material storage – materials obtained from any kind of commercial storage with used materials, stationary or online.
3. Construction work – materials obtained during any form of construction work (except demolition) like construction, reconstruction, expansion, renovation etc. Obtained material can be either used or it could be leftovers or extra pieces of new materials left that would otherwise become waste.
4. Leftovers – any residual building material or parts of materials that come from construction works or byproducts of new building materials.
5. Donated materials – any building material, used or new, donated to the new construction to prevent it from becoming waste

Presented possibilities can occur individually or together in a project if there is more than one type of ceramic material present. Each material may fulfill requirements for more than one source eg. shop display leftovers donated to a new construction – in this case, both leftovers and donation will be checked in the table.

Presented research was focused only on reusing architectural elements in the sense of reuse and preparation for reuse definitions featured in the Directive (EU) 2018/851 [13]. Because of that, cases in which recycled materials had been used were not taken into account.

For the purpose of this analysis the term “reuse” was divided into two categories: re-creation and transformation – both representing two different design strategies. The first approach reflects the reuse of materials according to their original purpose. It is possible for materials to undergo some minor adjustments, changes or cleaning but the main purpose of the material remains unchanged. The place of material implementation also remains unchanged, so it is the same as it was previously and as it was intended by the manufacturer. The second approach, on the other hand, is reusing materials by changing their purpose. In both cases, there is no interference with the structure of the primary material (as in the case of recycling) and the original element can still be recognized. The main difference between those two approaches is the place of material implementation and the way they were reused in the design of new objects. The third strategy – prevention – refers to every case where new materials or leftovers from production are used. That is because those materials are not technically reused, they are rather prevented from becoming waste. This strategy may occur together with one of those mentioned before to underline the way materials were used in new design. New materials have their purpose as well as those already used so it is possible to indicate if they were re-created or transformed in the new design. The last column in Table 2 refers to reuse drivers, understood as the reason that stands behind the choice to reuse building materials. Decision-making during the design process is very complex and there are a lot of different aspects that influence the final outcome. In [21] authors presented 6 main groups of reuse drivers based on literature review. It is a very detailed list of elements that can influence the decision for reuse but also a list of what factors favor making such a decision. However, in this paper the most important was the main general reason for reusing. Because of that only four drivers were selected:

Table 2.
Checklist for comparative analysis – overall building characteristics (source: author's elaboration)

no.	location					function					area [m²]	material					design startegy			reuse drivers			
	1- Europe 2- Asia 3 - North America 4 - South America 5 - Australia					1 - single family house 2 - multifamily house 3 - office 4 - cultural building 5 - commercial building						1 - demolition 2 - material storage 3 - construction work 4 - leftovers 5 - materials donated					1 - re-creation 2 - transforma-tion 3 - prevention			1 - ecological 2 - economical 3 - social 4 - visual			
	1	2	3	4	5	1	2	3	4	5		1	2	3	4	5	1	2	3	1	2	3	4
01					x	x					410	x					x	x				x	
02		x							x		30000	x						x				x	
03				x					x		92	x					x	x				x	
04		x								x	115	x			x		x		x	x			
05		x				x					520	x			x			x	x			x	x
06					x			x			410	x						x		x			
07		x							x		4970	x					x	x				x	x
08	x					x					129	x					x	x		x	x		x
09		x							x		10200	x					x			x			
10	x					x					160	x					x	x		x			x
11	x								x		1900	x						x		x			x
12	x						x				9148	x			x		x	x		x	x		x
13	x						x				1485	x			x	x		x	x	x		x	
14		x							x		1096	x					x	x			x		
15		x				x					612	x						x			x		
16	x								x		1000	x						x				x	x
17	x							x			1955	x						x				x	
18		x				x					250	x			x	x	x		x		x		
19	x						x				-	x						x		x	x		
20					x	x					220	x						x		x			
21					x	x					261	x					x	x		x			
22			x						x		800	x					x			x			
23	x					x					173000	x					x			x			
24	x					x					610	x					x			x			
25	x							x			-			x			x			x			x
26	x								x		19	x	x		x		x		x	x	x		
SUM	12	8	1	1	4	10	3	3	9	1	-	25	1	1	6	2	17	18	5	16	7	8	8

1. Ecological – aspects related to ecology, sustainable development, reduction of CO_2 emission, waste reduction and general care for the environment.
2. Economical – aspects related to limited budget and desire to reduce expenses.
3. Social – aspects related to historical context, heritage, memories.
4. Visual – choice of materials dictated only by the visual effect and the design idea.

They are focusing on sustainable perspective from which reusing has social, economic and environmental advantages [22]. To those three, a visual driver was added to emphasize the role of design itself in decision-making.

Detailed data about each material in every object was gathered as shown in Table 3. Again, data about material source was attached, taking into account that each of the material types present could have come from a different source. This table, however, delivers more details about the place of implementation of individual elements and their function - understood as its importance in the whole construction of a building. Each material can have a different function: structural, non-structural, finishing, insulation or installation. As a result, it was possible to observe if there were any changes between the original and final (after reuse) function of the material and if the fact of reusing material has any influence on its function in the construction process. After that, the original and final place of material implementation in the building was checked. The goal was to investigate whether the placement of the material changes after reuse.

3. RESULTS

The results of the comparison, performed in accordance with methodology described in section 2, are gathered in Table 3. It has been noticed that within the analyzed objects 4 main product categories can be found: bricks, roof tiles, tiles and ceramic rubble. Ceramic sanitary equipment was not included in this research because it was classified rather as an interior design element than a ceramic building material. The main source of these materials was demolition, observed in more than 75% of cases. It suggests that demolitions may be the most popular, or most accessible sources.

From the next column of the table it can be noted that the final place of implementation changed in the majority of cases. This results in transformation being the most frequently used design strategy. This particular result may seem counterintuitive since it should have been easier to reuse materials exactly the same way as they were used before. However, this outcome may have its origin in the desire the add some visual value to the new design. This way not only buildings are more ecological and sustainable, but also architects come up with new, interesting design solutions. Transforming materials by changing their original purpose seems to favour a more creative design process. It is probably also a result of many problems that can go along with the use of reclaimed materials.

In terms of material functionality within a construction, there is often a decline in the overall significance of the material when reused. For instance, a structural material may lose its functional or load-bearing importance and become non-structural or finishing upon reuse. It has to be noted that a lack of change in the material function does not have to be tantamount to a lack of change in material purpose. It is visible especially in the case of roof tiles which were initially classified as non-structural material. After reusing them as façade cladding they still have a non-structural function but their purpose has changed, so the transformation strategy has been applied.

Considering ways of incorporating reclaimed materials into the new design, some recurrent design patterns can be observed. In the reuse schemes for roof tiles, there is a repeatedly visible solution of placing them as façade cladding, especially with the additional function of sun breakers. Among analyzed projects there are many interesting examples, where the position of element in such construction can be adjusted during the day to let sunlight into the rooms. Less often, but equally interestingly, roof tiles can be reused as partition walls or interior walls finishing as it was in the case of project 16. Bricks can be implemented into the new design both by re-creation and transformation playing the role of interior walls, façade cladding, or wall and floor finishing. Tiles are usually reused as they were before, as a floor or wall finishing. However, there are also non-obvious approaches, for instance reuse as flower pots. Ceramic rubble is usually used in less visible form, as an aggregate for concrete, filling material for leveling the ground or some additional insulation as it happened in project 14.

What is common for all those cases in terms of design, is that reclaimed materials are gathered into large surfaces, e.g. on the façade, and not used individually, in small spots. The use of reclaimed materials is a strong point in each of the analyzed projects, standing out and highlighted as an advantage rather than hidden as a flaw.

Design patterns can also be seen in placing reused materials into new designs. Three main approaches can be applied which are presented in Figure 1. The first one occurs when single elements are reused exactly in the same way it was done originally. There is a part of the building, and after the demolition, all suitable elements are gathered and reimplemented into a new design exactly in the same way. This happened in projects 03, 07, 09, 11, 12, 14, 17, 19, 22-26. What has to be noted, is that the layout stays the same as originally but place of implementation can changed. For instance in project 19 roof tiles are placed on the façade but they were arranged in the same way as it happened originally on the roof. The second approach is when a new design consists of singular elements combined together as it was in the first solution, but this time single elements are reused with a change in their overall layout, usually by creating some visually interesting patterns. This method can be seen in the design of project no. 02, 06, 07, 09, 13, 14, 16, . The third approach involves creating units out of singular components which are then combined together into the final element. An example of this method can be found in project no. 01, 12, 20. Because of the strong bond between mortar and bricks an old façade was cut into square pieces and then after processing placed as a new façade.

Table 3.
Checklist with detailed data on each building material. (source: author's elaboration)

No.	type of element	material source					original place of implementation	final place of implementaton	original function					final function				design strategy		
		1 - demolition 2 - material storage 3 - construction work 4 - leftovers 5 - donated materials							1 - structural 2 - non-structural 3 - finishing 4 - insulation 5 - leftovers					1 - structural 2 - non-structural 3 - finishing 4 - insulation				1 - re-creation 2 - transformation 3 - prevention		
		1	2	3	4	5			1	2	3	4	5	1	2	3	4	1	2	3
01	bricks	x					construction walls	facade cladding	x						x				x	
02	bricks	x					construction walls	facade cladding	x						x				x	
	roof tiles	x					roof cladding	facade cladding		x					x				x	
03	bricks	x					construction walls	construction walls, floor, slab	x					x	x			x	x	
04	bricks				x		recycling leftovers	floor					x		x			x		x
05	tiles				x		samples (new material)	flower pot			x					x			x	x
06	roof tiles	x					roof cladding	facade cladding, sun breakers		x					x				x	
07	roof tiles	x					roof cladding	roof and facade cladding, sun breakers		x					x			x	x	
08	bricks	x					construction walls	walls finish, floor finish	x						x				x	
09	bricks	x					construction walls	construction walls, facade cladding	x						x			x		
10	bricks	x					construction walls	floor finish, chimney	x						x	x			x	
11	bricks	x					construction walls	facade cladding	x						x				x	
12	bricks	x					facade cladding	facade cladding	x						x				x	
13	bricks	x					construction walls	facade cladding	x						x				x	
	tiles				x	x	leftovers (new material)	walls finish			x					x				x
14	bricks	x					construction walls	facade cladding, partition walls	x						x			x	x	
	rubbel	x					construction walls	roof termal insulation	x						x		x		x	
15	roof tiles	x					roof cladding	facade cladding, sun breakers		x					x				x	
16	roof tiles	x					roof cladding	partition walls, walls finish		x					x				x	
17	bricks	x					construction walls	facade cladding	x						x				x	
18	bricks	x					construction walls	foundings	x					x					x	
	rubbel	x					construction walls	ground level elevation					x		x				x	
	tiles				x	x	shop display leftovers (new)	walls and floor finish			x					x		x		x
19	roof tiles	x					roof cladding	facade cladding		x					x				x	
20	bricks	x					construction walls	facade claddin	x						x				x	
21	tiles	x					floor finish	pavements			x				x				x	
22	bricks	x					construction and partition walls	partition walls	x					x				x		
23	bricks	x					facade cladding	facade cladding		x					x			x		
24	roof tiles	x					roof cladding	roof cladding		x					x			x		
25	tiles			x			terrace	terrace			x					x		x		
	tiles			x			walls finish	walls finish			x					x		x		
26	bricks	x	x				facade cladding	facade cladding		x					x			x		
	tiles	x					walls finish	walls finish			x					x		x		
	roof tiles				x		new materials leftovers	roof cladding		x					x			x		x

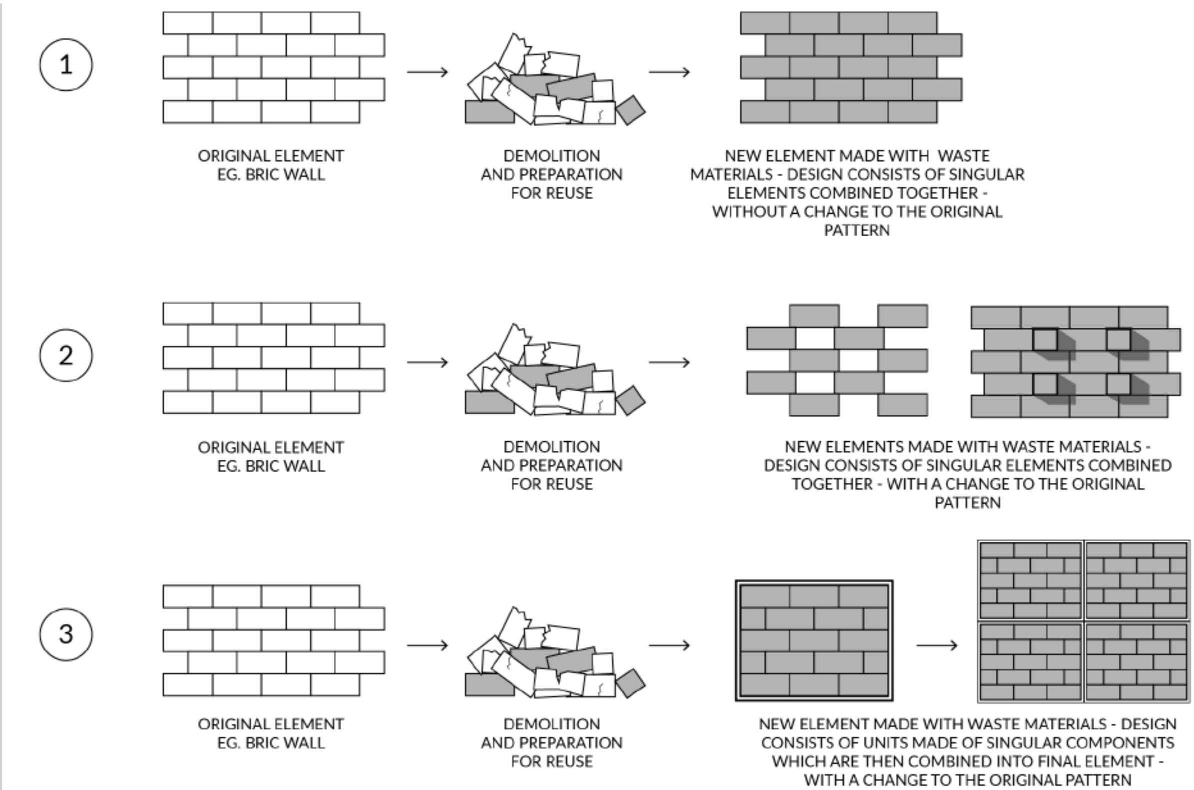

Figure 1
Recurring design patterns – main approaches. (source: author's elaboration)

4. CONCLUSIONS AND DISCUSSION

Presented design solutions for incorporating reused ceramic elements into new buildings, are an example of introducing circular economy principles into architectural design. Not only can reclaimed building materials be successfully implemented, but also can create interesting visual effects. This approach forces architects to reinvent the design process, adapt it to accessible sources of materials and then search for new ideas and technical solutions. Examples of architectural objects implementing this approach should be frequently presented and investigated to mark the trail for other architects and engineers that design with the reduced consumption of natural resources is the way towards waste prevention and a sustainable future.

Considering the results shown in this paper, developing special set of skills is crucial for an architect when dealing with reclaimed materials. As Gorgolewski mentioned [23], with such products nothing is obvious, starting from their availability and amount, ending their specifications. Therefore, it requires from the designer a change in approach and a lot of flexibility. It also requires building cooperation amongst engineers, architects, salvage companies and all the stakeholders of construction process.

The availability of products seems to play an important role in implementing reused building materials into new designs. Therefore, as demolition was a main source of obtained materials in case of analyzed buildings, good demolition practices should be developed and introduced into construction works. The most popular types of reused ceramic building materials should be considered during designing with reclaimed materials because of their availability and wide application possibilities.

What may be stated about recurring design patterns observed in this research is that they seem to be very versatile and applicable not only to ceramic materials. Other building material types should be examined in terms of the possibility of using the mentioned patterns.

There are various legal aspects to keep in mind when discussing materials reuse. Depending on world region, building type and specific product there might be different rules governing the possibility of reuse, obtaining materials certificates and their ability to be implemented into the market. In each of the presented cases, further considerations are required to account for specific law regulations of each country and their influence on the reuse approach applied.

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