Rubble Concrete – a material at times of crisis

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Rubble concrete provided the building material at the time of the crisis triggered by the Second World War. The contemporary crises of war in Ukraine and climate change shed new light on that experience. The processing of rubble into a new building material can be seen as ground-breaking with regards to the contemporary demands for a circular economy, including specifically urban mining, that is the extraction of valuable raw materials from anthropogenic waste, such as slag heaps and mine dumps.

Until recently, Kopiec Powstania Warszawskiego [Warsaw Uprising Mound] was considered a degraded area [1]. Its multifaceted regeneration required a multidisciplinary approach (and a design team) capable of combining seemingly disparate threads in a single project; these threats included the symbolic ones (the memory of the destruction and reconstruction of Warsaw after the 1944 Uprising), the natural ones (ruderal nature) and the architectural ones (the anthropogenic structure of the hill limiting its accessibility). The matter from which the mound was erected, namely rubble from buildings destroyed during the Warsaw Uprising and the rubble concrete produced from it – the historical material of the capital's reconstruction – became the key to synthesising these issues.

Rubble concrete provided a building material at the time of the crisis caused by the Second World War. The contemporary crises of war in Ukraine and climate change shed new light on that experience. The processing of rubble into a new building material can be seen as groundbreaking to contemporary demands for a circular economy, including specifically urban mining, that is the extraction of valuable raw materials from anthropogenic waste – slag heaps and mine dumps.

Currently, the use of concrete construction waste is among the key research topics in the field of sustainable construction. One such topic is concrete with recycled aggregate (RAC), the use of which in construction is permitted by Polish and European harmonised standards [2, 3], but which is still in the testing and prototyping phase. For this reason, the literature mainly focuses on analysing the technical properties of RAC [4] or its potential impact on the life cycle assessment (LCA) of the building [5]. Contemporary architectural aspects of the use of RCA are poorly recognised in the literature owing to the limited number of implementations.

The historical use of rubble concrete, especially in the reconstruction of Warsaw following World War II, as well as its social background, has been the subject of many years of research by Dr Adam Przywara [6, 7].

The first part of this publication presents the history of rubble concrete and its role in the reconstruction of Warsaw. The second part describes the process, inspired by rubble concrete, aimed at arriving at the contemporary version of rubble concrete developed and manufactured for the needs of the park on Kopiec Powstania Warszawskiego [Warsaw Uprising Mound].

Research Method

The study of the use of rubble concrete in the reconstruction of Warsaw was based on an analysis of reports and technical analyses by the Building Research Institute conducted between 1945 and 1951, the archival press and contemporary historical studies.

Additionally, a case study was performed on the use of contemporary rubble-concrete technology in the construction of retaining walls in the park at Kopiec Powstania Warszawskiego [Warsaw Uprising Mound]. This part of the work was based on the park design documentation, field observations of the works, such as rubble sorting and retaining wall erection, and practical experiments conducted both in laboratory conditions and on the construction site, the aim of which was to determine the optimal methods for integrating rubble into a modern concrete mixture.

Rubble concrete in reconstruction of Warsaw

Challenges of rubble removal

The inventory of the post-war destruction in Warsaw was performed by Biuro Odbudowy Stolicy (BOS) [the Bureau of Capital Reconstruction] in 1945–1946. It was estimated that the amount of rubble lying around the city stood at 20 million cubic metres. As Eugeniusz Olszewski wrote in the pages of Skarpa Warszawska, "two million wagons would have to be loaded to carry it away, which was 20 times more than the total pre-war annual import of any goods and raw materials into Warsaw" [trans. by the author] [8]. Within the structure of the BOS, Samodzielny Dział Gospodarki Gruzem [the

Independent Department of Debris Management] was created, the aim of which was to adopt a comprehensive approach to deconstruction. In view of the post-war destruction of the construction industry, BOS engineers quickly came to perceive rubble not only as a logistical problem but also as a potential raw material for reconstruction.

Development of rubble concrete technology: research and implementations

Firstly, whole bricks were recovered from rubble. For this purpose, manual demolition was ordered, which resulted in fewer bricks being damaged than if demolition was to be performed with ropes or machines [6]. However, the majority of the rubble mass consisted of wall fragments with damaged bricks. Their use entailed processing them into a new building material, namely rubble concrete. This was a new technology whose parallel development in several European countries was triggered by post-war realities. Warsaw engineers benefited from the experience of their foreign colleagues. Eng. Wacław Chyrosz translated the work entitled *Wykorzystanie gruzu ceglanego w odbudowie. Technologia i konstrukcje [The use of brick rubble in reconstruction. Technology and constructions]* from Russian [9]. On the other hand, the director of Instytut Badawczy Budownictwa (IBB) [the Building Research Institute], Eng. Antoni Kobyliński, made a study visit to Hamburg where he observed experimental structures of rubble concrete and the machines used in its production. The Institute published an illustrated report on this visit [10]. In parallel, domestic research on rubble concrete began. Bohdan Lewicki, under the supervision of Prof. W. Żenczykowski, defended his doctoral thesis entitled *Jednofrakcjowy gruzobeton [One-fraction rubble concrete]* at Politechnika Warszawska [Warsaw University of Technology]; in it, he presented study results on the material properties depending on the fraction of aggregate derived from the crushed brick rubble [11]. The IBB issued a series of publications devoted to rubble concrete, including a catalogue of rubble concrete products of which five experimental cottages were erected in Pole Mokotowskie [Mokotów Field], Warsaw in 1947. The houses, still inhabited today, were aimed at demonstrating the capabilities and limitations of each of the pilot products. The buildings were inhabited by the Institute's employees, who were obliged to conduct climatic (thermal and moisture) tests on rubble concrete [12]. The technology saw a very rapid development. This is evidenced by the model building of Towarzystwo Ubezpieczeniowe Warta [WARTA S.A. Insurance and Reinsurance Company] erected the following year at ul. Ordynacka 14, designed by Stefan Bohdan Lewandowski. The entire architectural decor of the edifice, including its cornices, fluted columns, framing of the openings and cladding was made as casts of rubble-concrete based on fine fractions of rubble mixed with sandstone dust [13]. The material used in this way, and its location close to Trakt Królewski [Warsaw Royal Route], suggests that the use of rubble concrete to reconstruct buildings in the historic area was being considered.

Photo 1. 'Muranów' rubble concrete breeze-block, manufactured until the 1950s; found at Kopiec Powstania Warszawskiego [Warsaw Uprising Mound]; source: the author

Use of rubble concrete in reconstruction

However, it was the fine prefabricated wall elements made of one-fraction rubble concrete that became, together with demolition bricks, the primary material used in the early phase of reconstruction. For the manufacturing of these elements, rubble sand, brick grit (as aggregate), Portland cement and water were used in different proportions depending on the type of product [14]. According to experts, the material had good thermal properties due to its porous structure. It was only applicable to erecting load-bearing walls up to a height of two storeys. In higher buildings, it was used as an infill for a reinforced concrete frame. The manufacturing took place at construction sites, including in such places as ul. Świętokrzyska (on the site of the current Ministerstwo Finansów [Ministry of Finance]), Zakłady Graficzne Dom Słowa Polskiego ["Polish Word House" Graphic Works] in Wola and the Praga I housing estate construction site. Machinery for the manufacturing of prefabricated elements was purchased in Switzerland in exchange for coal supplies [6, p. 84]. Rubble concrete breeze-blocks were used to build the housing estates of Muranów Południowy [Muranów South Housing Estate] (designed by Bohdan Lachert and his team), Koło II [Koło II Housing Estate] and Praga I [Praga I Housing Estate] (designed by Helena and Szymon Syrkus). Rubble concrete was also used for erecting public buildings, including the monumental estate of Ministerstwo Przemysłu i Handlu and Państwowa Komisja Planowania Gospodarczego [the Ministry of Industry and Trade and the State Economic Planning Commission] at Plac Trzech Krzyży (designed by Stanisław Bieńkuński and Stanisław Rychłowski) [6, p. 90]. Designers and politicians all emphasised the propaganda-related and symbolic potential of rubble-concrete in the context of post-war reconstruction, namely building on rubble and – literally – of rubble. Today, however, the materiality of rubble concrete remains silent. It has remained hidden under layers of plaster and sandstone, sometimes against the architects' original intentions. Assessing the full extent of the use of rubble concrete in post-war reconstruction is thus a difficult task.

End of rubble concrete production

As noted by Adam Przywara, PhD., the use of rubble concrete was rather reluctant, it was seen as a substitute for traditional building materials [6, p. 84]. Over time, its production was abandoned, although the experience gained was certainly used while implementing technologies to produce breeze-blocks from other waste materials, such as slag. The reasons why rubble concrete production was discontinued have not been investigated. The following can be considered as potential hypothetical explanations: (1) the progressive rubble removal from the city's central districts resulting in the exhaustion of the rubble raw material for production, (2) the decline in its suitability for processing

resulting from the sogginess it gradually gained in the years following the war end, (3) the re-emergence of the construction industry resulting in the supersedure of rubble concrete by traditional building materials, or – as suggested by the architect Maria Sołtys – (4) a systemic lack of servicing of machinery imported from the West.

Case study: retaining walls in the park at Kopiec Powstania Warszawskiego [Warsaw Uprising Mound]

Kopiec Powstania Warszawskiego [Warsaw Uprising Mound]: from wasteland to monument

Processing rubble into building materials failed to solve the problem of the rubble that covered the streets of the capital. The post-war rubble removal campaign preceded the implementation of rubble-concrete technology and had a significant impact on the shape of modern Warsaw. Józef Sigalin lists the methods for the use and disposal of rubble adopted by the BOS in 1945. These included: "1) backfilling of terrain depressions, clay pits, etc.; 2) regulating the banks of the Vistula; 3) overfilling low infertile areas of the right bank of Warsaw; 4) supplementing the terrain relief of the Vistula escarpment" [15]. It was the backfilling of wetlands and clay pits that resulted in the four artificial rubble hills - Stadion Dziesięciolecia [10th-Anniversary Stadium] (today's National Stadium), Górka Szczęśliwiecka [Szczęśliwicka Mount], Górka Moczydłowska [Moczydło Mount] and Kopiec Powstania Warszawskiego [Warsaw Uprising Mound]. The latter was used as a landfill site for the longest time and was therefore late to be developed. In 1980, Professor Longin Majdecki presented a project for a park at the mound. The plan failed to be implemented [16]. The area remained unused until 1994, when Eugeniusz Ajewski "Kotwa", a BOS architect and a veteran of the Warsaw Uprising, together with Światowy Związek Żołnierzy Armii Krajowej [World Association of Home Army Soldiers], led to the erection of a monument in the form of the Fighting Poland Anchor sign on top of the mound. Over the next few years, the monument surroundings were provided with basic amenities - a paved square and an outdoor staircase from ul. Bartycka. In 2000, Rada Gminy Warszawa-Centrum [the Council of the Warsaw-Centre Municipality] adopted a local spatial development plan, in which the construction of a "city park according to an individual design [trans. by the author]" in the mound area [17] was established, and in 2004, the Warsaw City Council adopted a resolution to name the mound "Kopiec Powstania Warszawskiego [Warsaw Uprising Mound" [18]. In 2018, the mound was included in the municipal register of monuments. The provisions of the local plan remained unimplemented for the following two decades. During this time, the surroundings of the hill underwent intensive urbanisation, which was not followed by the development of greenery areas. Therefore, in 2018, Miasto Stołeczne Warszawa [the City of Warsaw] issued public consultations and a public BioBlitz nature inventory; in 2019, an architectural competition for the development of the mound was announced. The competition jury selected the design by the consortium of topoScape sp. z o.o. and Archigrest sp. z o.o. studios, drawn up under the supervision of landscape architects Justyna Dziedziejko and Magdalena Wnęk and architects Marcin Maraszek and Maciej Kaufman. The construction work was conducted on its basis by the consortium of Remondis Sp. z o.o. and Sorted Sp. z o.o. and lasted from 2021 to 2023.

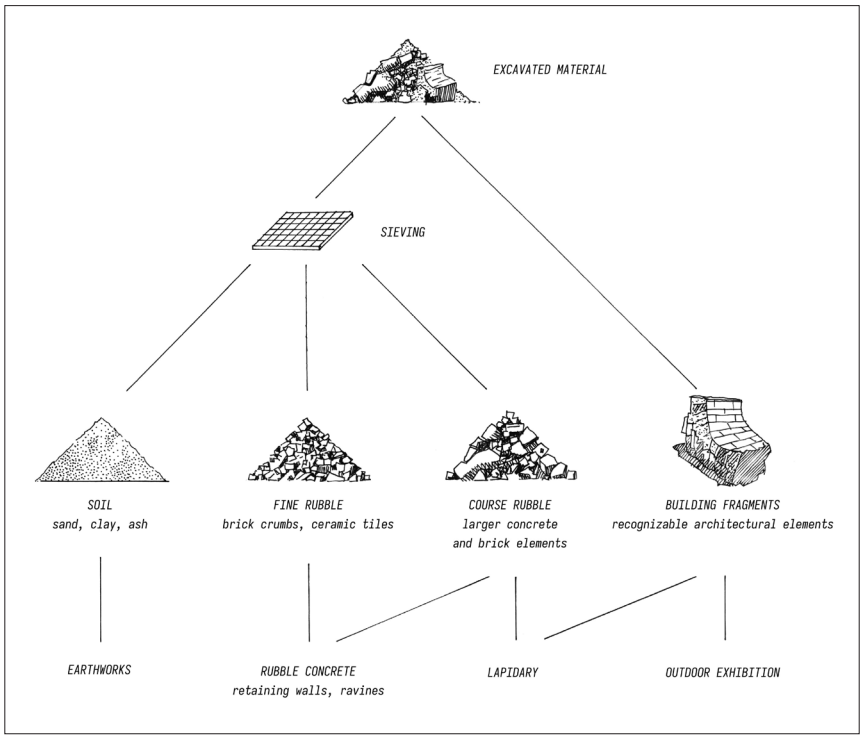

Fig. 1. Kopiec Powstania Warszawskiego [Warsaw Uprising Mound], rubble management; source: the author

Photo 2. Fragment of a brick arch exposed in the park; source: Michał Szlaga

Rubble management strategy

Kopiec Powstania Warszawskiego [Warsaw Uprising Mound] is an artificial hill whose

relative height equals 40 m (123.8 m above sea level), and which covers an area of about 8 ha and has a volume estimated at 855,000 m^3, i.e. about 4.3% of the amount of post-war debris in Warsaw estimated by BOS. According to the decision of the Capital Conservator of Monuments, "earth masses from the Mound obtained as a result of excavation, ground levelling, new planting, etc. should be developed in situ, within the project area. It would be unacceptable in conservation terms to treat them as construction waste" [trans. by the author] [19]. The volume of excavated material extracted in this way during the construction works amounted to 13,200 m^3. Although this amount stands for only about 1.5 percent of the total volume of the mound, its management on the limited site became a challenge for the designers and the contractor. To comply with the above guidelines, a rubble management strategy was adopted at the design stage to separate the excavated output into fractions subsequently used for different types of structures. Large lumps of rubble in which fragments of buildings could be recognised, such as sections of brick arches, chimneys, etc., were first to be separated. The most interesting of these were collected on the construction site and were catalogued with the view to displaying them on the site as witnesses to history. The less characteristic pieces were placed in the so-called Lapidarium – eight four-and-a-half-metre baskets shaped in the form of a labyrinth, which also served as the background for an outdoor historical exhibition. Most of the excavated material was put in a drum sorter, where the loose fraction (earth, clay, dust, sand) was separated from fragments of bricks, stove tiles and other larger elements. The loose material was used to form the site, while leftover construction materials were placed in Lapidarium baskets, built

Photo 3. Filling the Lapidarium baskets with rubble during construction works in 2022; source: Archigrest sp. z o.o. [Limited company]

Photo 4. Lapidarium - gabion baskets filled with rubble excavated during earthworks; source: Michał Szlaga

Photo 5. Separation of rubble from loose fractions of excavated material on site using a drum sorter, March 2022; source: Marcin Maraszek

Photo 6. Rubble separated from excavated earthworks, the construction site of the park at Kopiec Powstania Warszawskiego [Warsaw Uprising Mound], 2022; source: Archigrest sp. z o.o. [Limited company].

Photo 7. Inlaid works in rubble concrete - street name plaque found in excavation; source: the author

Photo 8. "Geological" texture of retaining walls of rubble concrete. Visible rubble inlaid works; source: Archigrest sp. z o.o. [Limited company]

into retaining walls, or placed in rainwater drainage fields. Some of them also served as a substrate for a so-called "ruderal meadow" sown with the use of a seed mixture developed based on the pioneering work entitled "Roślinność ruderalna na gruzach miast Polski [Ruderal vegetation on the ruins of Polish cities]" from 1949, by Prof. Roman Kobendza, a botanist [20].

Interventions in the mound structure: retaining walls

The 2019 competition guidelines emphasised communication and accessibility: "providing access to the top of the mound for the elderly, the disabled and families with children", and "ensuring free communication throughout the area". The guidelines also called for the creation of a representative zone at the foot of the hill and "improving the stability of the slopes and escarpments, e.g. by reinforcing the existing escarpments with gabion baskets, retaining walls, grids filled with soil" [1]. Given the low awareness of the anthropogenic morphology of the mound, it was suggested to "display the structure of the mound by performing a localised exposure of rubble that was then protected against adverse weather conditions" [trans. by the author] [21].

All these threads were successfully combined by building retaining walls in the plinth zone of the mound and an artificial "ravine" with which to bridge the hitherto unconnected embankment terraces located at different levels. In view of the adopted assumption to strive for maximum preservation of the existing stand of trees and the complicated ground conditions, many ground reinforcement technologies that required wide excavations, such as ground reinforcement and gabion baskets, were excluded at the outset. In order to account for the requirement that the underlying rubble should be exposed, rammed earth technology was initially considered. However, due to its low resistance to lateral soil pressure and water erosion, this concept was rejected after specialist consultation. Referring to the history of the Kopiec Powstania [Warsaw Uprising Mound] being a witness to the rebuilding of Warsaw, it was decided to make an attempt at implementing modern rubble concrete technology using rubble from earthworks.

Photo 9. Retaining wall od rubble concrete in the plinth zone of the Mound; source: Michał Szlaga

Contemporary rubble concrete

The Polish Standards allow the use of crushed concrete as aggregate for a new concrete mix. This can be either 1) aggregates gained by washing fresh concrete, 2) by crushing hardened concrete that has not been previously used in construction or 3) recycled aggregate (from material previously used in construction) [2]. Depending on the exposure class of the concrete, the proportion of recycled aggregate can reach up to 50 percent of the weight of coarse aggregate. The standards limit the possibility of using aggregate obtained from ceramic masonry elements (bricks and tiles) [3]. The predominance of bricks in the material separated from the excavated material provided one of the reasons for which the use of rubble was discontinued. In addition, the excavated rubble was damp and crumbly and thus it could potentially compromise the technical performance of the mix. In collaboration with mgr inż. Krzysztof Kuniczuk, a concrete technologist, a concrete mix was designed using waste and recycled aggregates other than the aggregate from the mound (up to 50% of the weight of aggregate), which would then incorporate the rubble found on site - in the form of inlaid work so as not to affect

the load-bearing capacity of the structure [22]. Numerous samples – under laboratory and on-site conditions – were made prior to the work commencement. Additionally, the technology was refined during the construction work by making many adjustments in close cooperation between the designer and the contractor. The artisanal way of erecting the walls was crucial to the result achieved; thus, the contractor appointed a permanent team of six workers for the works connected to the construction. The team manually layered the thick concrete mixture in formwork, alternating it with layers of sand about 20-30 cm high. The workers then selected lumps of rubble of various sizes and placed them in the formwork. The elements used included stove tiles, floor tiles, bricks, balustrade balusters or a street name plaque. A day's work ended with the crew laying a sloping layer to connect the newest (highest layer) to the lowest layer made as the first layer on that day. In this way, 'tectonic faults' were created in the artificial 'stratigraphy' of the mound. Once the formwork was dismantled, the sand was mechanically removed. Subsequent wall sections were continually accepted by the site designer supervisor. The result was the "presentation of the structure of the mound" postulated in the competition guidelines, in the form of an artificial rock of a sort having a deep, quasi-natural texture that was, in fact, a record of the daily work of the workers (faults) and their aesthetic choices (inlaid work).

Bioreceptive urban rock

The structural design of the retaining walls on the mound was developed by engineers Krzysztof Guraj and Paweł Komorek. They were divided into two types. The first type, with a deviation of 10 degrees from the vertical position stands at a height of up to 4 metres; due to the significant loads, it required a reinforced concrete load-bearing core. Walls of this type were used in the plinth area of the mound. The second type of retaining walls, with a variable slope of 40 to 60 degrees, were laid directly on the trench wall. In this type of walls, used in the remaining areas of the park, rubble concrete provides the actual bearing layer. The walls are provided with drainage, but are not waterproofed, so as to enable the penetration of groundwater pushing in from the slope. Type two walls are not dilated, which can result in the occurrence of natural cracking as the structure settles and the mound slope works. The structures are bioreceptive, which means that they provide potential habitat for pioneer plants. Therefore, the final stage of the work involved the introduction of mosses. Following the project specifications, this was done by spraying a spore mixture, developed by the landscape architects, together with a nutrient solution in the form of a suspension of water and buttermilk. The spores were obtained by collecting turfs of mosses overgrowing the debris in the mound area and then grinding them with the nutrient solution. The suspension was applied with a sprayer device to selected surfaces that offered a suitable microclimate. After one year, it can be seen that the mosses have adapted well and began colonising further niches of the structure.

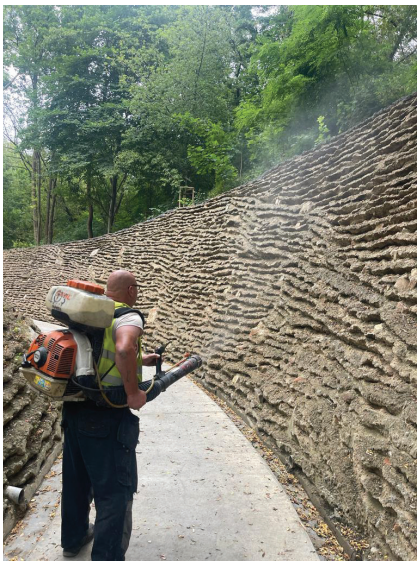

Photo 10. Moss introduction carried out with a sprayer device in 2023; source: Piotr Michalak

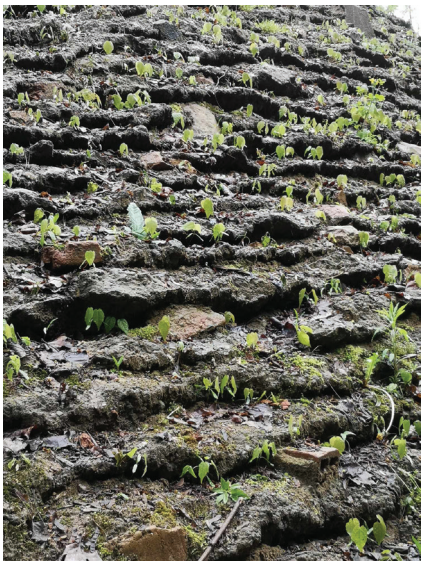

Photo 11. Bioreceptivity of rubble concrete: mosses introduced during construction and Acer Negudo seedlings in 2024; source: topoScape sp. z o.o. [Limted company]

Photo 12. 'Ravine' with walls of rubble concrete; source: Michal Szlaga

Conclusion

Conservation requirements influenced the decision to adopt a closed cycle of building materials on the construction site of the park at Kopiec Powstania Warszawskiego [Warsaw Uprising Mound]. This significantly impacted design decisions and the subsequent construction process, in which the designers and the contractor, operating on a very limited scale, faced challenges similar to those surrounding the reconstruction of the capital. A strategy and technology adopted enabled using all the excavated material from the earthworks as raw material, after it had been separated into fractions. The material was reused to form the relief and, in the form of rubble concrete, to erect engineering facilities. In contrast to the historical buildings made of rubble concrete, this material remained exposed in the park as a witness to the destruction and reconstruction of the city, as well as to reveal the anthropogenic structure of the hill and a potential habitat for pioneer vegetation.

Beyond the technical aspects, the symbolic meaning of constructing from rubble became important. In this semantic aspect, the confirmed sense of the use of material transformed the space, making it a symbolic place. It was the participation of matter and the truth of the object that gave it meaning [22]. Despite the historical references, contemporary concrete with recycled aggregate (RAC) cannot be based on historical technology. Standards make it practically impossible to use crushed brick, which provided the basic ingredient (aggregate) of rubble concrete and also served as the main component of postwar rubble. The substitutable use of modern construction waste, that is concrete rubble, partially solves the problem of raw material exploitation and increasing landfill volumes, but it fails to lead to significant reductions in carbon dioxide emissions. In both cases, the emissions problem remains unresolved, as it is directly related to the type of binder used for the concrete mix rather than the aggregate. Replacing Portland cement with low-carbon binders is a major challenge for the construction industry today. This aspect, however, goes beyond the scope of this article.

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ABSTRACT:

The article discusses the significant issue of using rubble concrete in contemporary architecture. The author presents the use of rubble concrete in the process of rebuilding Warsaw following the Second World War as a historical context. The publication presents a case study of a park at Kopiec Powstania Warszawskiego [Warsaw Uprising Mound] in the Polish capital. Rubble concrete emerged as a building material in response to the crisis resulting from the collapse of the construction industry, as well as the need to remove the rubble of the destroyed city. Kopiec Powstania Warszawskiego [Warsaw Uprising Mound] served as a storage area for this rubble. Between 2021 and 2023, it was transformed into a public urban park. In order to improve the accessibility of the area, modern retaining walls were erected using specially developed rubble concrete technology. The article describes both the modern rubble concrete technology itself and its symbolic and ecological significance.

KEYWORDS:

rubble concrete, urban mining, recycling, Kopiec Powstania Warszawskiego [Warsaw Uprising Mound]

STRESZCZENIE:

GRUZOBETON – MATERIAŁ CZASÓW KRYZYSU. Artykuł omawia istotną kwestię zastosowania gruzobetonu we współczesnej architekturze. Autor prezentuje wykorzystanie gruzobetonu w procesie odbudowy Warszawy po II wojnie światowej jako kontekst historyczny. Publikacja przedstawia studium przypadku parku na Kopcu Powstania Warszawskiego w stolicy Polski. Gruzobeton został stworzony jako materiał budowlany w odpowiedzi na kryzys związany z załamaniem przemysłu budowlanego oraz koniecznością usunięcia gruzów zniszczonego miasta. Kopiec Powstania Warszawskiego służył jako miejsce składowania tego gruzu. W latach 2021–2023 przekształcono go w publiczny park miejski. Aby poprawić dostępność terenu, zastosowano nowoczesne ściany oporowe z użyciem specjalnie opracowanej technologii gruzobetonowej. W artykule opisano zarówno samą technologię współczesnego gruzobetonu, jak i jej symboliczne oraz ekologiczne znaczenie.

SŁOWA KLUCZOWE:

gruzobeton, miejskie górnictwo, recykling, Kopiec Powstania Warszawskiego