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REVIEW PAPER

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MOTTAINAI IN CIVIL ENGINEERING – A MESSAGE FROM JAPAN

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ABSTRACT

This article examines the impact of Japan's *mottainai* concept on civil engineering practices, focusing on the waste of materials, financial resources, and harmonisation of structures with the environment. The authors highlight the global challenges of environmental and social imbalances in the context of global warming. The Japanese concept of *mottainai* is presented as the key to shaping the civil engineering approach. The inefficient use of raw materials was analysed in terms of material waste. A transition to a closed-loop economy is recommended, emphasising the need for resource efficiency. In the context of financial resources, the need for efficient budget allocation and project management is emphasised. The section on harmonising structures with the environment focuses on aesthetics, environment, sustainable mobility, and an integrated approach to urban planning. Civil engineering projects should combine functional efficiency with respect to the environment, and the *mottainai* concept can be a tool for achieving sustainability in civil engineering. Innovative solutions, such as intelligent energy management systems, are recommended to improve construction efficiency.

Keywords: civil engineering, material wastage, sustainability, construction, closed-loop economy

INTRODUCTION

Global studies suggest that humans have significantly upset the balance between nature and society, and that they should be aware of the environmental impact of their actions, given the consequences of global warming for the entire world (Kimata & Takahashi, 2020; Kimata & Takahashi, 2022; Syvitski et al., 2022). As people change their lifestyles, values, places of residence, and means of transportation, civil engineering must adapt to these changes in order to avoid serious problems related to waste – called *mottainai* in Japanese – and climate change. Speaking of *mottainai* in civil engineering, it's about adapting to the changes taking place in the world, such as how and where people will live and how people and goods will be transported in the future (Tokat & Taş, 2022).

The Japanese expression *mottainai* can be translated as 'What a waste!' or 'Don't waste!'. *Mottainai* means much more. It expresses concern or regret for what has been wasted because its intrinsic value has not been properly utilised. Buddhism and Japan's indigenous religion, Shinto, are integral parts of the Japanese psyche, which is why the non-human world is experienced and lived in everyday life. In the Japanese worldview, everything in nature is endowed with spirit; each individual existence is dependent on others, and everyone is interconnected in an ever-changing world (Sato, 2017; Kinefuchi, 2018; Rayhan, 2023).

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Currently, *mottainai* is reflected in Japan's approach to environmental protection and sustainability. This term is used to promote resource conservation and discourage waste. Japanese people are taught from an early age to conserve water, electricity, and other precious resources (Rayhan, 2023). Japan's experience can serve as a model for other regions of the world to improve their practices and achieve sustainability goals. By analysing the Japanese model, valuable lessons can be learned and applied to many European countries, especially Central Europe. Japan's success in instilling these principles from an early age positioned it as a model for global sustainability. When applying the *mottainai* experience to European countries, particularly Central Europe, cultural nuances must be considered. Adaptation involves collaborative efforts, including awareness campaigns and policy initiatives, tailored to the unique challenges and opportunities in Central Europe. By fostering cross-cultural exchanges and leveraging successful waste management practices, the aim is to cultivate a shared commitment to sustainability on a global scale.

Figure 1 illustrates how the concept of *mottainai* contributes to a more comprehensive approach to the Sustainable Development Goals (SDGs). In comparison to the traditional '3Rs' of 'reuse, reduce, and recycle' (Mohammed, Shafiq, Abdallah, Ayoub & Haruna, 2020), *mottainai* incorporates a fourth 'R'of 'respect' (Xiang & Li, 2021). This addition emphasises cultural and ethical dimensions, enriches the sustainability framework, and fosters a deeper connection between individuals and the environment.

The concept of *mottainai* has influenced environmental campaigns in Japan and beyond, for example through the work of the late Nobel laureate and founder of the African Green Belt Movement, Wangari Maathai (Suzuki, 2013; Kinefuchi, 2018; Mutua & Omori, 2018). The relationship between resource use and societal well-being extends in several directions. Inadequate and unevenly distributed resources can lead to political and economic conflicts, and environmental problems (McManus Warnell & Umeda, 2019). The role of civil engineering in the use of natural resources is one of the most important activities for achieving a sustainable future.

The mission of civil engineering is to build infrastructure that serves society. Therefore, civil engineers must pay attention to all the factors that can affect people's lives, identify the interactions between these factors, and understand the world as an integrated system comprising all these interactions (Terzano, 2023). In other words, we need to think in terms of systems theory. Many projects currently planned or underway will still be in use by 2050. Therefore, civil engineers must take the lead in carefully considering the future of civil engineering.

Civil engineering plays a key role in shaping (transforming) the environment, and the concept of *mottainai* can be a valuable lens through which the effectiveness and sustainability of engineering practices can be evaluated. This article focuses on the Japanese cultural values of *mottainai* (referring to the avoidance of undesirable actions), taking into account both material and financial resources, as well as the long-term impact of building structures on their surroundings – the environment.

Fig. 1. *Mottainai* – A message from Japan to the world

Source: Kimonoboy (2023) modified by the authors.

WASTAGE OF MATERIALS AND MACHINERY

Concerns about the devastating environmental impacts of construction processes (e.g. energy and material consumption, waste and dust generation, and air and water pollution) have led to increased awareness of the need for sustainable construction practices (Son, Kim,

Chong & Chou, 2011). In civil engineering, the judicious use of materials and machinery is of paramount importance for sustainable and responsible construction practices (Son et al., 2011; Terzano, 2023). *Mottainai* highlights the waste that occurs when these resources are used inefficiently (Xiang & Li, 2021).

Inefficient use of materials

Currently, unprecedented amounts of fossil material minerals are extracted and consumed from the Earth's crust (Stephan & Athanassiadis, 2018). The global extraction of non-metallic minerals (gravel, sand, clay, limestone, and gypsum) reached approximately 35 billion tonnes in 2010. Sand and gravel accounted for the bulk of the world's non-metallic mineral extraction in 2010 (40.8% gravel and 31.1% sand), (Miatto, Schandl, Fishman & Tanikawa, 2017; Ghaffar Burman & Braimah, 2020). The main end-users of this consumption are infrastructure investments and major construction projects. The transition to a closed-loop economy, in which production flows can be reintegrated as secondary resources, is a promising solution for the construction industry (Stephan and Athanassiadis, 2018; Ghaffar et al., 2020).

Wastage of material often results from poor planning, inaccurate estimates, and inadequate recycling practices. The waste of materials as a consequence of the inefficient use of materials increases the cost of investment (construction projects), negatively impacts the environment (environmental degradation), and increases the carbon footprint.

To minimise the environmental impact, it is essential to implement advanced modelling and simulation tools to accurately estimate materials (Keulemans, Harle, Hashimoto & Mugavin, 2020), use sustainable, natural (Fig. 2), and recycled materials (Murray, 2019), and integrate sustainable construction principles to reduce the environmental impact of materials and waste generation (Ghaffar et al., 2020; Mohammed et al., 2020; Udomsap & Hallinger, 2020).

Suboptimal placement of machines

Construction work often involves the use of heavy machinery, and its inefficient deployment can lead to a significant waste of resources (Lewis, Karimi, Shan & Rasdorf, 2019; Rashid & Louis, 2019; Huang, Fan, Shen & Du, 2021). Errors in the use of machinery, including overreliance on heavy equipment, lack of maintenance, and inadequate operator training, have a direct impact on project timelines, costs, and environmental impacts.

To optimise construction work, the regular maintenance of machinery and equipment is recommended to ensure optimal machine performance and durability. Important elements include training programs for machine operators to increase productivity and reduce errors and the integration of advanced technologies, such as the use of building information modelling (BIM), to optimise machine placement and project management planning (Akinosho et al., 2020; Rahimian, Seyedzadeh, Oliver, Rodriguez & Dawood, 2020).

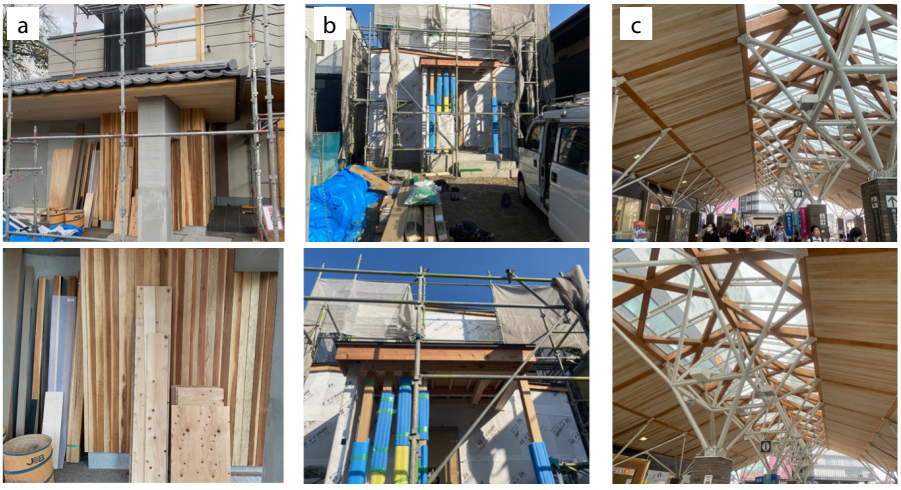

Fig. 2. Use of sustainable and natural materials in construction: a – residential house; b – office building; c – train station

Source: photos by Magdalena Daria Vaverková, Okayama, 2023.

Environmental consequences

A key issue is the environmental impact of the waste materials and machinery. Improper disposal and management of construction waste, machine emissions and construction activities contribute to environmental degradation (Jalaei, Zoghi & Khoshand, 2019; Barbhuiya & Das, 2023). This underscores the need for a holistic approach to mitigate these consequences and promote environmental responsible construction practices (Pham & Kim, 2019; Shurrab, Hussain & Khan, 2019; Avotra, Chenyun, Yongmin, Lijuan & Nawaz, 2021).

It is important to implement waste management plans that encourage recycling and minimise landfilling (Joensuu, Edelman & Saari, 2020; Kabirifar, Mojtahedi, Wang & Tam, 2020). Use of low-carbon and energy-efficient machinery and recycling materials to reduce carbon footprint.

A detailed understanding of the waste of materials and machinery in civil engineering, setting it in the context of *mottainai*, should involve analysing the various dimensions of inefficiency (Terzano, 2023). There should be a dialogue on sustainable construction practices aiming for a future in which resource use is seamlessly combined with human responsibility for the environment.

WASTAGE OF FINANCIAL RESOURCES

In civil engineering, efficient allocation of financial resources is integral to project success (Pan & Zhang, 2021). Financial resources are often allocated to various elements of a construction project, ranging from materials and labour to equipment and contingency funds. The consequences of misallocating budgets such as cost overruns, delays, and reduced quality have a major impact on construction projects. Inefficient financial management has a negative impact on project performance, underscoring the need for precise budget planning and risk identification (Lyu, Sun, Shen & Zhou, 2019; Siraj & Fayek, 2019; El khatib et al., 2022).

It is essential to implement robust project management software to ensure accurate budget tracking and analysis. Regular audits should be conducted to ensure adherence to budget allocations and timely identification of discrepancies. It is also necessary to create contingency funds for unforeseen circumstances, limiting disruption to the overall financial plan.

HARMONISATION OF THE BUILDING WITH THE SURROUNDINGS

In today's world, where climate change is becoming increasingly obvious, the harmonisation of buildings with the environment is becoming a key element of sustainable development. In the concept of *mottainai*, harmonisation with the environment in civil engineering projects can be seen as a deeper understanding and respect for the relationship between people and the environment (Bao, Lee & Lu, 2020; Berglund et al., 2020). Vitková and Lemak (2021) emphasised the importance of a thoughtful strategy for this harmonisation, especially in urban environments, to mitigate negative climate impacts. Saroop and Allopi (2013) further emphasised the role of engineers in the design of environmentally sustainable infrastructure and the use of green technologies. Zavadskas, Vilutienė and Tamošaitienė (2017) emphasised the need for sustainable construction processes to minimise environmental impacts. Together, these studies emphasise the importance of harmonising construction with the environment in civil engineering projects, and the potential of this approach to contribute to sustainable development.

Aesthetic and environmental aspects

Civil engineering projects should not only meet functional requirements, but also harmoniously blend with the surrounding landscape. The aesthetic aspects of designs are important for integration with the surroundings (Shahi, Esfahani, Bachmann & Haas, 2020; De Medici, 2021; Lucchi, Baiani & Altamura, 2023). Designers and engineers should consider the local landscape features, history, and culture to avoid compromising the integrity of their surroundings. Gluch (2005) emphasises the need for construction to move away from product-centered action toward process-centered action, which is consistent with the concept of *mottainai*. Both Voskresenskaya, Vorona-Slivinskaya and Panov (2018), and Opoku, Agyekum and Ayarkwa (2019) emphasise the importance of environmental sustainability in construction,

Opoku et al. (2019) mainly identifies factors such as customer expectations, and Voskresenskaya, Vorona-Slivinskaya and Panov (2018) emphasises the need for innovative approaches to environmental protection. Subbotin (2019) additionally draws attention to the role of building materials and technologies in achieving both architectural and environmental goals, which can be linked to *mottainai* and efficient use of resources and aesthetic appeal (Fig. 3).

Fig. 3. Examples of efficient use of resources and aesthetic appeal of interior architecture using Okayama University facilities as an example

Source: photos by Magdalena Daria Vaverková, Okayama, 2023.

In the context of *mottainai*, infrastructure design must not only be purely functional but also respect the beauty of the surrounding nature (Jimura, 2023; Terzano, 2023). The aesthetic aspects of design become an expression of respect for nature, just as the Japanese concept of *mottainai* expresses care for what has been given to us.

'Kengo Kuma and Associates undertook the development of a wooden classroom for Okayama University in Japan. The project was assembled with a specific focus on enhancing education on wood construction techniques and providing an informative learning environment for students pursuing studies in this field. This "Wooden Classroom" concept for Okayama University illustrates the potential of timber construction. Beyond its role as an educational space, the project encourages reflection on sustainable architectural innovations by involving students and observers in envisioning eco-friendly design solutions. Architects integrated a transparent glass canopy and fused Cross Laminated Timber (CLT) components with steel elements to emphasize the versatility of wood in combination with other materials' (Petridou, 2023). Figure 4 showcases the architectural innovation in the development of a wooden classroom. This project, designed to advance education on wood construction techniques, emphasises creating an immersive and informative learning environment for students specialising in this field. This depiction underscores the potential of timber construction in promoting sustainable architecture and educational initiatives, making it a noteworthy case study for eco-friendly design and construction practices.

Fig. 4. Kengo Kuma's pillar-free wooden classroom boosts eco-friendly designs at Okayama University

Source: photos by Magdalena Daria Vaverková, Okayama, 2023.

Successful harmonisation with the environment requires consideration of a project's impact on ecosystems and sustainability. The use of green technologies, such as eco-friendly building materials (Jimura, 2023), natural water treatment systems, and green roofs, can minimise the negative impact of infrastructure on the local environment (Shi & Liu, 2019; Liu & Li, 2023; Wamane, 2023). In addition, strategies that take into account the rehabilitation and development of areas after construction work is completed are key to restoring ecological balance.

Mottainai formulates a call to avoid wasting resources, and sustainable practices in civil engineering are a perfect reflection of this approach. The selection of environmentally friendly materials, sustainable transportation solutions and diligence in land use planning are all actions that eliminate wasteful use of resources.

Integrated approach to urban planning and sustainable mobility

Integrated spatial planning considers the needs of both people and nature to be key to sustainable development (Huser, 2011; Liu & Zhou, 2021). This approach requires the full integration and assessment of environmental, social, and economic issues (Eggenberger & Partidário, 2000). It also involves harmonising the natural environment in architectural spaces, as seen in the work of Frank Lloyd Wright (Emelianov, Bakaeva & Zuleta, 2019; Vaughan & Ostwald, 2022). Integrating ecosystem services into urban planning can help protect key habitats and support the provision of these services (Grêt-Regamey, Altwegg, Sirén, van Strien & Weibel, 2017).

Integrating sustainability principles into construction projects, including the maintenance of natural ecological corridors and a balanced urban natural environment, is crucial for improved project implementation (Ochieng, 2014). Effectively planned green infrastructure can contribute to social well-being and sustainable urban development (Plata, Elías Orozco & Villaseñor, 2019). The strategy of building roads as 'aesthetic greenways' in China, emphasising the protection of natural habitats and the promotion of local tourism and economic growth, can serve as a model for balancing environmental and socioeconomic

needs (Cheng, Lv, Zhan, Su & Cao, 2015). The construction of urban ecological corridors, which require a spatial approach to balance ecological protection and economic development, is particularly important for sustainable urban development (Peng, Zhao & Liu, 2017).

Civil engineering projects should focus on sustainable mobility and accessibility. Creating bicycle paths, developing public transport systems, and promoting pedestrian zones are elements that not only reduce the negative impact on the environment but also create friendly and accessible spaces for the community (Fig. 5).

Tiwari (1999) underscored the necessity of establishing secure infrastructure for non-motorised modes, such as pedestrians and cyclists, to enhance the effectiveness of public transport. Building on this, Curtis (2008) highlighted the significance of sustainable accessibility and advocated a fundamental shift in urban development to bolster both efficient public and private transport systems. Similarly, Giduthuri (2015) and Un-Habitat (2015) emphasised the importance of urban planning and design, which prioritise accessibility and sustainable transport modes, such as cycle paths and pedestrian zones. Collectively, these studies emphasise the pivotal role of sustainable mobility and accessibility in civil engineering projects, not only in mitigating environmental impacts, but also in crafting inclusive and efficient urban spaces.

In the spirit of *mottainai*, integrated spatial planning has become a joint effort between society and the natural environment.

Education and social participation

Aboelata, Ersoylu and Cohen (2011), and Kamel and Lim (2012) emphasised the importance of community involvement in sustainable engineering projects, emphasising the need for engineers to understand and address the problems of local communities. This can be achieved through the development of specific competencies as well as the use of appropriate engagement mechanisms. Johnston, Caswell and Armitage (2007) further emphasised the role of education in increasing environmental awareness among engineers, suggesting the use of real projects to implement sustainable

Fig. 5. Sustainable mobility and availability of bicycle parking in Japan

Source: photos by Vaverková, 2022/2023, Igor Vaverka, 2023.

development principles. Fernandes, Rangel, Alves and Neto (2019), and Keirl (2020) highlighted the role of design and technology education in promoting a sustainable global future. Collectively, these studies highlight the importance of community education and engagement in achieving environmental harmonisation in engineering and architectural design.

In the context of *mottainai*, the harmonisation of buildings with their surroundings is not only an end in itself, but also a means to avoid waste in a wide range of engineering and architectural activities. It is an expression of concern for all aspects of the environment, where resources are valued, and harmony between humans and nature is the basic principle of development (Maltseva, Kaganovich & Lorentz, 2018; Khaing, 2020). Moreover, the role of construction and architecture in promoting unity with nature is emphasised, with the design of environmentally friendly spaces and improvement of the microclimate being key aspects of this harmonisation (Emelianov et al., 2019).

FEATURES AND PERFORMANCE IN THE CONTEXT OF *MOTTAINAI*

In the context of *mottainai*, the functions and performance of civil engineering projects have become key aspects that combine efficiency with respect to resources and the environment. Civil engineering projects should be guided by not only functionality but also sustainable design goals. The functional value of the structures should be achieved with minimal environmental impact. The application of innovative solutions such as smart energy management systems or efficient lighting systems can enhance the functional performance of buildings (Gagnon, Leduc & Savard, 2014; Pan & Zhang, 2021; Kim et al., 2021).

Implementing energy-efficient solutions, in line with the concept of *mottainai*, is a key aspect of sustainable development. Both Zavalani (2011) and Gagliano (2014) emphasise significant energy savings achievable through the adoption of energy management systems and alternative energy generation and conservation systems in buildings. Mutani and Vicentini (2015) further underscored the importance of local authorities in promoting and encouraging private investments in energy-efficient solutions, especially in urban areas. However, Feng (2019) highlighted the challenges associated with implementing these solutions in warm climates, suggesting the need for educational programs, enhanced regulations, and financial incentives. Collectively, these studies underscore the potential of energy-efficient solutions to reduce operational costs and environmental impacts. They also emphasised the need for supportive policies and development strategies, taking into account the broader utilisation of renewable energy sources such as solar panels, heat pumps, and small wind turbines. Solutions based on closed-loop systems, particularly for the utilisation of water and certain types of waste, are also crucial.

CONCLUSIONS

In the context of civil engineering, the concept of *mottainai* has become a guiding philosophy for construction practices in a sustainable and responsible manner, avoiding waste. By analysing the aspects of material and machine waste, improper allocation of financial resources, and harmonisation with the environment, architects and civil engineers can achieve investment efficiency goals while respecting the environment. *Mottainai* can become a key opportunity for the development of civil engineering and sustainable construction. By focusing on minimising resource waste, applying sustainable construction practices, and integrating projects with the natural and social environment, civil engineering can be not only efficient, but also in line with the spirit of the *mottainai* concept. It requires collective efforts from society, business, and science directed towards a future where human development harmonises with environmental protection, and resources are valued and used with discretion. Such efforts can improve human living conditions and mitigate the effects of climate change on Earth.

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Authors' contributions

Conceptualisation: M.D.V., Y.M. and I.V.; validation: M.D.V., Y.M. and I.V.; writing – original draft preparation: M.D.V. and I.V.; writing – review and editing: M.D.V. and Y.M.; visualisation: M.D.V.

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MOTTAINAI W INŻYNIERII LĄDOWEJ – PRZESŁANIE Z JAPONII DLA ŚWIATA

STRESZCZENIE

Artykuł analizuje wpływ japońskiej koncepcji *mottainai* na praktyki inżynierii lądowej, skupiając się na marnotrawstwie materiałów, zasobów finansowych i harmonizacji budowli z otoczeniem. Autorzy podkreślają globalne wyzwania związane z zaburzeniem równowagi między środowiskiem a społeczeństwem w kontekście globalnego ocieplenia. Japońskie pojęcie *mottainai* jest przedstawione jako kluczowe w kształtowaniu podejścia inżynierii lądowej. W obszarze marnotrawstwa materiałów analizuje nieefektywne wykorzystanie surowców. Zaleca się przejście na gospodarkę o obiegu zamkniętym, podkreślając konieczność efektywnego gospodarowania zasobami. W kontekście zasobów finansowych podkreślono potrzebę efektywnej alokacji budżetów i zarządzania projektami. Sekcja dotycząca harmonizacji budowli z otoczeniem skupia się na aspektach estetycznych, środowiskowych, zrównoważonej mobilności i zintegrowanym podejściu do planowania przestrzennego. Projekty inżynierii lądowej powinny łączyć efektywność funkcjonalną z poszanowaniem dla środowiska, a koncepcja *mottainai* może stanowić narzędzie do osiągnięcia zrównoważonego rozwoju w inżynierii lądowej. Zaleca się stosowanie innowacyjnych rozwiązań takich jak inteligentne systemy zarządzania energią w celu poprawy wydajności konstrukcji.

Słowa kluczowe: inżynieria lądowa, marnotrawstwo materiałów, zrównoważony rozwój, budownictwo, gospodarka o obiegu zamkniętym