ISSN 2286-4822
www.euacademic.org

EUROPEAN ACADEMIC RESEARCH
Vol. IX, Issue 4/ July 2021

Impact Factor: 3.4546 (UIF)
DRJI Value: 5.9 (B+)

The circular economy applied to the production and use of soil-cement bricks in small towns in the Amazon

LILYANNE ROCHA GARCEZ
Doctoral student in Materials Science and Technology at the University State Paulista and professor at the Federal University of Amazonas
https://orcid.org/0000-0002-8349-9614
ELLEM CRISTIANE MORAES DE SOUSA CONTENTE
PhD in Society and Culture in the Amazon and professor at the Federal University of Amazonas
HOSANA EMÍLIA SARMENTO COSTA LEITE
Doctoral student in Civil Engineering in the field of geotechnics and professor at the Federal Institute of Pernambuco
JOÃO DE ALMEIDA MELO FILHO
PhD in Civil Engineering in the field of Structure and Materials and professor at the Federal University of Amazonas
MIGUEL ÁNGEL RAMIREZ GIL
PhD and Associate Professor in Ceramic Materials at the Department of Materials and Technology at University State Paulista
https://orcid.org/0000-0002-2681-1579

Abstract

Political-social aspects of the State of Amazonas raise a notion of diversity and complexity due to its geographic, ecological, and economic features, as well as extensive areas that portray the abundance of water and forests in its territory. Some sectors such as civil construction are influenced by this regionality, mainly in terms of available materials and logistics for transporting these materials to the localities. In this sense, this work presents the technical and environmental feasibility of the production and consumption of soil-cement bricks for municipalities located in the Amazon region, analyzing these criteria through the biomimetic approach of the circular economy. It is noteworthy, therefore, that the soil-cement brick technology may enable the reduction of negative impacts on the environment and the cost of construction, especially in small towns.

Keywords*:* Amazon regionality, Ecological brick, Civil construction, Environmental impacts, Biomimetic approach.

1. SOCIAL AND REGIONAL ASPECTS OF SMALL TOWNS IN THE STATE OF AMAZONAS

Life in Amazonian cities is linked to rivers and forests. The local peculiarities, by any means, are diverse and complex, considering the ecological and environmental characteristics (such as the abundance of water and the biodiversity of the vegetation in its territory), but also the geopolitical, ethnic, cultural, social, and economical aspects.

Studies that prioritize the hierarchical system of Brazilian cities generally use population groups for the terminology of small, medium, and large cities. Thus, the class of small towns includes those with up to 20,000 inhabitants. Above this amount, cities with up to 500,000 inhabitants are classified as medium. Finally, those cities with more than 500,000 inhabitants are considered large. In the specific case of the State of Amazonas, except for one large city that is the capital Manaus, 40% of other cities are considered small, while the remaining 60% of Amazonian cities are medium-sized. In the latter case, all of them with less than 120 thousand inhabitants (SCHOR et al., 2016).

The State of Amazonas has a total surface area of 1,559,167,878 km^2 with an estimated population of 4,207,714 inhabitants. In addition, inversely to its size, and in spite of its population characteristics, the State represents about 2% of the country's population, constituting a demographic density of 2.23 inhab./km^2, being the second smallest among the federation units (IBGE, 2020).

The main access to cities in the interior of Amazonas are the navigable routes of its river network, in which the regional transport vessels sometimes influence the circulation demand related to air transport. This geography constituted by rivers, streams and *paranás* allows the circulation and flow of vessels even without an adequate waterway structure. But due to its natural characteristics, the river offers navigability. Thus, the use of waterway modal transport is an essential activity for the social integration of inland cities.

However, due to its immense extension, the distances between municipalities or riverside communities are generally very large, which makes it difficult to move between these locations due to the lack of infrastructure in the transport sector. On the other hand, few municipalities in the state are connected by land with the capital Manaus. Thus, most municipalities have restricted access to goods and services, made difficult by boat trips that can last up to fifteen days.

The economy of the State's municipalities is based on plant, mineral and animal extraction. Compared with other locations in Brazil, the state has less industrialized cities, however, these cities are rich in terms of biodiversity, due to the Amazon Forest. Despite the existence of the Manaus Free Trade Zone industrial hub, the main economic activity is linked to primary activities, which generally correspond to production that adds little value to the product. In the mineral extraction, mainly limestone and tin are obtained; in vegetal extraction there is the logging activity, collection of regional fruits, rubber and in the animal extraction, fishing. These small towns have development vulnerabilities due to their low capacity of generating resources and presenting themselves as possibilities for accessing services and employment opportunities, where the rural area lacks in infrastructure and basic services (LIMA et al., 2017).

Besides economy, another relevant highlight is the impact caused by livestock and agriculture, which points to intense logging, large-scale transport, and energy infrastructure projects and, on a smaller scale, although not negligible, the mineral exploration. The environmental impacts caused by deforestation, for example, also include the loss of opportunities for the sustainable use of the forest (ROQUETE, 2019).

Deforestation, whether motivated by agriculture, livestock, selective logging or those associated with other purposes causes environmental impacts, and its effects lead to changes in the composition and structure of populations of flora and fauna species, as well as in the ecosystem’s properties. (CHAZDON, 2012).

2. THE CERAMIC BRICK INDUSTRY IN THE METROPOLITAN REGION OF MANAUS (MRM)

The Metropolitan Region of Manaus – MRM has about 2.7 million inhabitants and represents a strategic area for the development of the State (IBGE, 2020). It is the largest regional wealth hub and centralizes the command of large private equity, housing one of the most important industrial complexes in the country, shopping centers, financial institutions, and large areas for agricultural and agroindustrial projects.

The MRM houses the largest number of ceramic and pottery industries in the state. This number of industries places the municipality of Iranduba in a prominent situation in the production of red ceramics – mainly conventional bricks – with 18 factories. In other quantities are the municipalities of Manacapuru, with 9 production units, followed by Novo Airão, Tefé, Itacoatiara, Tabatinga and Parintins with one factory at each of them. The ceramic-potter pole of Amazonas is comprised by the municipalities of Iranduba and Manacapuru, both included in the MRM, which together have 27 ceramic factories (MACIEL, 2013).

The clay deposits are located very close to the industrial facilities, some in the pottery's own premises. Clay is usually extracted from August to December, when the rivers ebb, forcing a large amount of raw material to be kept in stock to work year-round in the production of red ceramics (CAMPELO et al., 2004).

The fuels most used by the red ceramic factories in the ceramic-potter pole are firewood, sawdust and wood chips. Wood pallets are also used to a lesser extent. All these residues are responsible for burning the ceramic body, helping as direct fuels (MAGALHÃES, 2016).

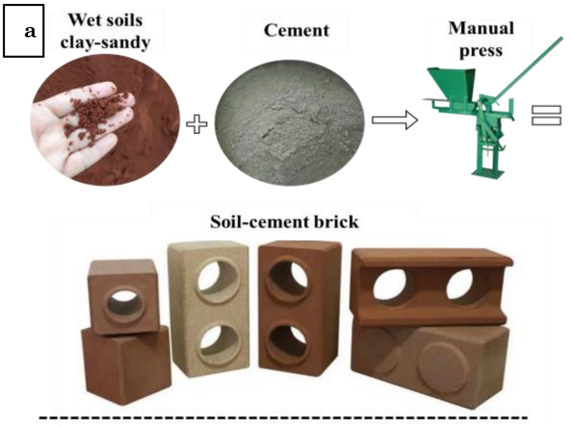
For the sale of bricks to municipalities in the state, they are transported from the factories by truck to the city of Manaus and, in the port area, thousands of them are shipped on ferries that navigate the rivers in periods of flood (March to August) and can take up to 30 days to reach the most distant locations, such as the triple border Brazil x Peru x Colombia or the final locations in rivers Juruá, Jutaí and Purus (bordering with the State of Acre).

3. CERAMIC SOIL-CEMENT BRICKS

Ceramic soil-cement bricks are currently being studied for presenting themselves as an alternative, energy-efficient and sustainable product. França et al. (2018a) explained about the modular constructions of pressed soil-cement bricks that are gaining ground in civil construction, since these bricks present environmental and economic advantages when compared to the constructions with standard ceramic bricks.

Sasui et al. (2018) considered the need to use cement in ceramic bricks for better soil stabilization, because with the mixture, hydration reactions of silicates and aluminates present in the cement occur through the formation of the gel that fills part of the voids in the mass and joins the adjacent particles of the ground, giving it initial resistance.

Typically, the advantages of soil-cement bricks are environmental benefits, simple production and good fire resistance. Due to the shape of the brick, the construction process is simple, and highly specialized work is usually not necessary. The main materials are wet sandy soil and Portland cement, which are mixed and compacted in a manual press and can have various formats (Figure 1a). The Figure 1b presents a standard brick scheme with its main measurements. As burning is not necessary after brick formation, production significantly reduces energy costs compared to production of conventional clay bricks (KONGKAJUN et al., 2020).



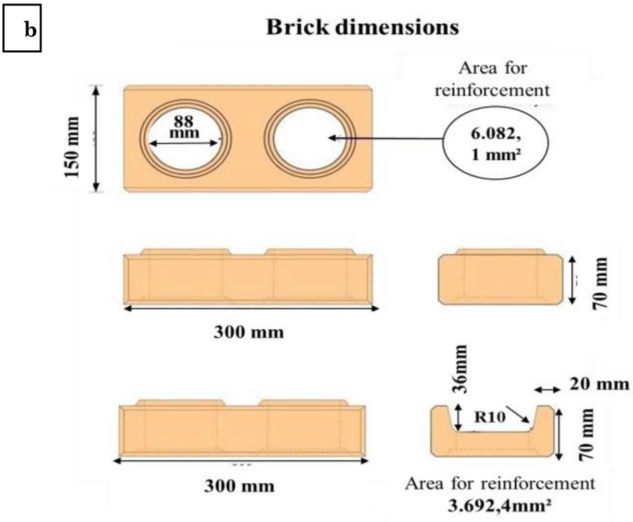


Figure 1. (a) Materials, construction and dimensions of the soil-cement brick and (b) main measures of the soil-cement brick adopted by the market
Source: Author himself.

As for the construction process, the highlighted benefits are the way the piece is installed in the building and proper brick configuration. Due to the hollow format, the soil-cement brick favors the filling of the supporting columns more easily and quickly (CÂNDIDO et al., 2020). In addition, the pieces facilitate the passage of electrical and hydraulic ducts due to their internal holes and, consequently, dismisses the method used in traditional masonry, eliminating the need of cuts in walls and easing the execution of this stage of construction avoiding waste in breaking walls (LÔBO et al., 2020). Another advantage of holes in bricks is that they form thermo-acoustic chambers that control the temperature inside the building, help on noise isolation and protect the environment from noise pollution (FRANÇA et al., 2018b).

The construction costs are also minimized in terms of specialized services, such as the insertion of steel in the support columns. There are savings in carpentry labor and also the excessive use of wood for templates is made unnecessary, as the columns are supported by steel through their holes, making the weight of the masonry to be distributed over the walls, creating a lighter and safer structural masonry.

It is worth noting that the soil-cement brick can also be reused if there are crazing, cracks or breaks during the production process, for they can be crushed, generating raw material compound. Also, during construction, it is possible to control the loss of parts, as the modular masonry allows for the minimization of waste, greater cleaning and organization, without accumulating debris.

The construction of masonry using soil-cement bricks does not require labor with some specificities and qualifications. Sometimes, nearby deposits are used to obtain soil, reducing transport and material costs. Combined with the reduction in construction time and savings on materials such as masonry mortars, soil-cement bricks have special features such as the formulation of blocks with sockets that optimize the construction time, as well as reduces loss and waste arising from any breakages.

In Brazil, the soil-cement brick has been used for years with some structural restrictions, but representing cost reduction, less environmental impact, less energy consumption and, also, materials with high pozzolanicity[1] rates or mechanical improvements (CAMPOS et al., 2019).

3.1. Environmental aspect of soil-cement brick

The manufacture of conventional ceramic bricks is an essential part of the construction industry, but it contributes heavily to environmental degradation. As pointed out by Martins Barros et al. (2020) a brick kiln emits about 70-282 g of carbon dioxide, 0.001-0.29 g of black carbon, 0.29-5.78 g of carbon monoxide and 0.15-1.56 g of particulate matter per kilogram of baked bricks, depending on the kind of soil and fuel spent.

The soil-cement brick has advantages regarding the criterion in environmental adequacy since its principle is less degradation to the environment when compared to the conventional brick. It is more economically viable too, assuming a cost reduction in civil construction

---

[1] Siliceous or siliceous-aluminous material that is finely ground which, in the presence of water, reacts with calcium hydroxide forming compounds with cementitious properties.

due to the abundance of its raw material, along other factors such as the reduction of material waste during its production and even during execution of the work.

For Kongkajun et al. (2020) soil-cement bricks are attractive for housing construction, especially in developing countries. They are usually prepared from Portland cement and locally available soil. They present ecological benefits, good thermo-acoustic performance, in addition to being resistant, durable and low-cost. In addition, they do not need to be baked and do not require finishing.

It is noteworthy that the production of brick is done through a press, where there is no heat treatment. The curing process is done by natural drying, eliminating the use of firewood and disposal of polluting gases, generating less aggressiveness to the environment, which does not occur in the production of conventional bricks, as there is a baking process that is responsible for the excessive emission of gases in ceramic factories. Furthermore, there is a large amount of energy consumed during the production of conventional bricks, bringing the cost of this energy to a significant percentage of the total production costs.

Another relevant point is the chemical stabilization of soils by adding binders such as cement, used in the manufacture of soil-cement bricks, as they increase their mechanical properties and reduce their susceptibility to moisture variations. An advantage of soil-cement bricks is the possibility of adding other materials to the mixture, mainly residues, an important factor for sustainable construction (FERREIRA et al., 2020). For example, the addition of coconut fiber powder or rice husk is cited, in which the mechanical strength and water absorption properties in soil-cement are not affected if any of these agro-industrial residues replace the cement up to 10% (MACHADO et al., 2020).

Several researchers used rice husk ash (FUNDI et al., 2018) and sugarcane bagasse ash (SHAFIQ et al., 2014) in soil-cement bricks, demonstrating the effectiveness of ash as a pozzolanic agglomerate in the formation of the microstructure of the soil-cement system, as well as the relationship between its microstructure with the properties found from the effective mixtures.

Pozzolanic ashes from agro-industrial residues, such as rice husk and sugarcane bagasse, when applied in soil and cement mixtures, can be effective for a better filler effect[2], density reduction, increase in mechanical strength, improving workability of the mixture and, when it presents pozzolanic characteristics, it also promotes a decrease on the amount of cement used (GARCEZ and LEITE, 2020).

4. CIRCULAR ECONOMY MODEL FOR ENVIRONMENTAL ANALYSIS

The term "sustainable development" contains two key concepts: the priority of basic needs and the limitation of natural resources (HUMMELS and ARGYROU, 2021). These two concepts, added to the concept of economic development, converge to sustainable development with a systemic view focused on the balanced integration of economic, social, and environmental systems (FOSTER et al., 2016).

One of the solutions that considers the minimization of environmental impacts in a systemic way and encompasses the production model as a whole is the Circular Economy. The Circular Economy proposes, in general terms, the reinsertion of waste in the production cycle, aiming to minimize the deposition in the environment and consequently avoiding the generation of negative environmental impacts (FOSTER et al., 2016).

The Circular Economy advocates the use of renewable energy, monitoring, minimization and elimination of toxic products and the eradication of waste (EMF, 2012). Morseletto (2020) defines Circular Economy as an "economic model aimed at the efficient use of resources through waste minimization, long-term value retention, reduction of primary resources and closed circuits of products, parts and materials within limits of environmental protection and socioeconomic benefits". The frameworks that often serve as tools in evaluating the progress of the Circular Economy include Life Cycle Assessment and Material Flow Analysis, considering that the environmental and economic

---

[2] Particles of small diameter and spherical shape, when repelled by ion difference, tends to insert themselves between the cement grains (HERMANN et al., 2016; IMAM & SRIVASTAVA, 2018).

dimensions of sustainability are in line with the principles of the Circular Economy (PRIYADARSHINI and ABHILASH, 2020).

The following schools of thought participate in the construction of the concept of Circular Economy: Regenerative Design; Performance Economy (STAHEL, 2010); Cradle to Cradle (BRAUNGART and MCDONOUGH, 2014); Industrial Ecology (CLIFT and DRUCKMAN, 2016); Biomimetics (BENYUS, 2003); Natural Capitalism (HAWKEN et al., 2000); and Blue Economy (PAULI, 2010).

The Biomimetic approach presented by Benyus (2003) consists in imitating the models, systems, and elements of nature with the purpose of solving complex human problems, as long as they are sustainable. Biomimetics is based on three fundamental principles: nature as a model, nature as a measure, and nature as the mentor of a learning process. Edwin Datschefski, a name inextricably linked to the development of Biomimicry (DATCHEFSKI, 2001), emphasizes the principles of biomimicry as:

- Cyclic: products must be part of natural cycles, such as a closed recycling circle.
- Solar: all energy used in the production and use of the product must come from renewable energy.
- Efficient: increasing efficiency in the use of materials and energy means less environmental damage.
- Safety: products and by-products must not contain toxic materials.
- Social: the manufacture of products cannot include exploitation of workers.

4.1. The biomimetic approach applied to the production and use of soil-cement brick in the Amazon region

The concept of sustainable development implies a reformulation of the vision of the environmental impact caused by human activities, incorporating all those resulting from production and consumption activities since extraction, industrial processing, transport, until destination of waste arising from these activities.

Thus, the use and development of soil-cement brick technology is in line with one of the greatest challenges imposed on researchers, professionals, and society: the reduction of environmental impacts arising from activities in the construction sector. Thus, as for the environmental aspects, an analogy will be made with the Biomimetic approach of the circular economy, in the cyclical, solar, efficient, safe and social principles.

Considering that products must be part of natural cycles, such as a closed recycling circle, Segantini and Wada (2011) point out that, unlike conventional bricks, which do not allow reuse when damaged in the production cycle, soil-cement bricks can be crushed and immediately reused in the manufacture of new bricks, consequently not generating waste generation in their production.

Soil is the main raw material of the brick, and the characteristic pedological aspect of the soil in the State of Amazonas is of the latosol type, predominantly constituted by fine-grained clays of the kaolinite type. Other areas indicate a soil having as main minerals: quartz, kaolinite, goethite, hematite, anatase and maghemite with a majoritarian presence of kaolinite and quartz. Granulometry shows that the soils feature a good structure with a predominance of clay, but containing silt and sand (NEGREIROS et al., 2020).

With these characteristics, it is worth noting that the main raw material for making the brick is found in virtually all municipalities in the state, in which the localities would need to adapt in terms of extracting deposits and obtaining cement. Among these and other advantages, it is estimated that the soil-cement brick can provide a reduction of 30 to 40% in the final cost of a construction.

Another significant aspect is related to the environmental gains arising from changes in technology and energy matrix, such as the reduction of CO_2 emission levels and, especially, the reduction in deforestation of species in the region for the extraction of firewood, with the preservation of biodiversity and generation of sustainable resources in forests, as well as the possibilities of producing soil-cement bricks in small municipalities, which would not be dependent of the MRM for masonry constructions and buildings.

Soil-cement brick research has helped to reduce energy use and subsequent CO^2 emissions from the baking of conventional bricks. These aspects present the minimization of energy input, use of raw materials and production of pollutants in the production process (OTI and KINUTHIA, 2012).

The production of conventional bricks uses, on average, 2 kWh of energy and releases about 0.41 kg of carbon dioxide per brick (FERREIRA et al., 2018). Therefore, the benefits of the soil-cement brick – which include lower greenhouse gas emissions – are highlighted. Furthermore, the use of other pozzolanic materials such as ash from agro-industrial residues for soil stabilization can potentially result in reduced extraction/energy consumption during extraction of conventional binders such as cement (OTI and KINUTHIA, 2012).

According to data from the United Nations Environmental Program (UNEP, 2012) civil construction accounts for 30% of the emissions that cause global warming, 40% of the energy generated worldwide per year, extracts 30% of materials from the environment, consumes 25% of water and generates 25% of solid waste.

In this sense, soil-cement bricks can be an alternative that requires low energy consumption during the extraction of the raw material, since they can be produced with the soil from the local constructions, avoiding occasional transportation problems (LEONEL et al.; 2017; BARBOSA et al., 2019).

It is also reiterated that the Amazon Region has little seasonal thermal amplitude. As it is located close to the equatorial band, it receives, throughout the year, a high incidence of solar radiation, which is reflected in high temperatures regardless of the seasons. Two seasonal periods occur at different month intervals in the region and are popularly called rainy and dry (with a lower total rainfall) (ALEIXO and SILVA NETO, 2019). In this context, the benefit to the production process can be highlighted due to the use of room temperature for the natural drying of the soil-cement brick.

The efficiency of civil construction carried out with soil-cement bricks demonstrates a reduction in cost, less environmental impact, less energy consumption, good thermo-acoustic performance, with extremely low levels of waste. It is emphasized that the soil-cement brick can bring benefits to the environment, without large proportions of negative impacts generated by civil construction. In its production process and even in the transport of raw material, the amount of prevention that this material makes is remarkable when compared to other masonry materials.

These bricks can be explored for energy efficient masonry wall construction and potentially aid current trends in the development of green and flexible products. Furthermore, the application of pozzolanic agro-industrial residues on bricks generally does not cause direct environmental pollution during the entire life cycle of the brick nor direct effect on climate change (BHAIRAPPANAVAR et al., 2021).

Using residual pozzolanic materials to replace cement is a possible practical solution that addresses the issues of sustainable construction and environmental concerns relevant to the production of building materials, being possible to provide a lower resource-saving structure than conventional bricks (POORVEEKAN et al., 2021).

The market, production process and work safety of conventional ceramics commonly have low qualifications of labor, as most of them are workers fresh out of the riverside sector who see in the industrial segment a less degrading job and with less seasonality, whilst facing absorption difficulties in other sectors.

However, next to units with greater product diversification and a higher level of automation that demand more specialized workers, the low qualification of the workforce imposes itself as a loss, not only for production, but also constituting an obstacle to the automation process itself. Furthermore, the lack of a policy for training and updating workers leaves them vulnerable in the strategic stages of production, such as the baking of products, due to the difficulty in dealing with the ovens (ALVES et al., 2021).

The production activities are tiring, aggravated by noise levels, exposure to the heat of the ovens, unfavorable ergonomic conditions for lifting and manually transporting loads, and the imposed work rate. It is reiterated in this context that the worker becomes vulnerable to safety issues and factors that undermine health due to working conditions that require strict enforcement of legislation (PEREIRA et al., 2021).

The soil-cement brick is a product resulting from the compacted mixture of soil, binder and water. It has several advantages such as the simplicity of production that can be done using simple and low-cost equipment like mixers and compactors for molding (ANDRADE et al., 2021). In the case of artisanal (or manual) production, a place is needed to mix and apply the mixed material into the press (Figure 1). It does not need specialized labor, since with training it is possible to handle the equipment and there is no need of a baking process similar to conventional bricks, which also avoids the impacts caused by this manufacturing process, such as noise and thermal discomfort.

Therefore, it becomes necessary to carry out ergonomic improvements in the environment that can be applied in an easy and practical way to any worker. It is also reiterated that the soil is not a contaminating material and is the component with the greatest volume in the production of bricks, reiterating that this production can be carried out with local soil and avoids transportation logistics. As clay-based materials are inert and non-toxic, their use in bricks generally does not cause direct environmental pollution during the brick's life cycle (BHAIRAPPANAVAR et al., 2021). Cement, on the other hand, contributes with much smaller amounts, ranging from 5% to 10% of the soil mass, enough to stabilize it and give it the desired strength properties.

In the construction process, the use of soil-cement bricks has positive characteristics, such as its shape allowing the fitting of one over another, it has holes in its geometry that allow the passage of beams and pipes, saves the use of mortar and concrete, reducing the generation of debris and, mainly, ease of use for workers in the masonry construction stage (TEIXEIRA et al., 2021).

Due to the peculiar characteristics of small municipalities in the Amazon region, it must be considered that the production of local soil-cement bricks will bring social benefits to these locations, taking into account that this production is more suitable for cases where there is a difficulty of access to logistics and availability infrastructure. (CALDAS and TOLEDO FILHO, 2021).

In this context, a significant feature is related to the environmental gains arising from technological and energy matrix changes, such as the reduction in CO2 emission levels and especially the reduction in deforestation of regional species for the extraction of firewood, with the preservation of biodiversity and the generation of sustainable resources in forests, but mainly to the possibilities of producing soil-cement bricks in the small municipalities themselves, which will not depend only on the MRM for masonry constructions and buildings.

5. CONCLUSIONS

The conducted analysis points to the technical feasibility in the production and consumption of soil-cement bricks without a structural function, whose technological application can make it possible to reduce the negative impacts on the environment and the cost of construction. In addition, the materials used to produce soil-cement bricks can be easily found, and the production process can be carried out easily, especially at medium and small locations.

It is noteworthy that the social, geographic, educational, and technical dimensions, in the general context of the Amazon region, portray some difficulties in the performance of civil engineering, especially with regard to traffic logistics for access to locations, the lack of supplies, as well as some limitations related to the infrastructure of small municipalities, typical of the region. Therefore, the relevance of research in the search for greater knowledge and efficiency in sustainable materials and production processes is quite significant.

REFERENCES

1. ALEIXO, Natacha Cíntia Regina e SILVA NETO, João Cândido André. **Rainfall characterization of the Middle Solimões-AM**. ACTA Geográfica, Boa Vista, v.13, n.31, Pp. 104-120, 2019.
2. ALVES, Christiane Luci Bezerra; PAULO, Evanio Mascarenhas; KHAN, Ahmad Saeed. **Ambiente de trabalho no setor de cerâmica vermelha: notas para a Região Metropolitana do Cariri – CE.** Revista de Economia Regional Urbana e do Trabalho. Volume 10, Número 1. pp. 27 – 48, 2021.
3. ANDRADE, Suelen Silva Figueiredo; LEAL, Jéniffer Paloma da Cruz; BRITO, Virgínia Limeira Lopes; BATISTA, Larissa Santana; LIMA, Giovanna Feitosa de. **Avaliação do impacto na durabilidade de tijolos solo-cal devido a incorporação de resíduos de demolição da construção civil.** 4º Congresso Sul Americano de Resíduos e Sustentabilidade. Gramado – RS. 2021.
4. BARBOSA, Andrezza de Melo; REBELO, Viviane Siqueira Magalhães; MARTORANO, Lucieta Guerreiro; GIACON, Virginia Mansanares. **Characterization of acai waste particles for civil construction use.** Revista Materia, V. 24, N. 3, 2019.
5. BENYUS, Janine M. **Biomimética: Inovação Inspirada pela Natureza.** 1ª Ed., São Paulo: Cultrix, 2003.

6. BHAIRAPPANAVAR, Shruti; LIU, Rui; SHAKOOR, Abdul**. Eco-friendly dredged material-cement bricks.** Construction and Building Materials, Nº 271, paper 121524, 2021.
7. BRAUNGART, Michael e MCDONOUGH, William. BONALDO, Frederico (Tradutor). **Cradle to Cradle**: criar e reciclar ilimitadamente. Editora: Gustavo Gili; 1ª edição, São Paulo, 2014.
8. CALDAS, Lucas Rosse e TOLEDO FILHO, Romildo Dias. **Avaliação ambiental do sistema construtivo de alvenaria de blocos de solo-cimento considerando diferentes especificações de projeto.** Gestão & Tecnologia de Projetos. São Carlos, v16, n2, 2021. https://doi.org/10.11606/gtp.v16i2.161978
9. CÂNDIDO, Lucas William Felipe; ALMEIDA, Zilda Caboclo de; FRANCO, Claudinéia Conationi da Silva; VITTO, Daniel Malheiros; ROCHA, Enoque Alves da; PINTO JUNIOR, Joaquim Mario de Paula; VALENCIO, Jorge Luiz Rodrigues; MARTINS, Maria Silvinha Cararo; DORNE, Sandra Regina; ROCHA, Silvana Soares Siqueira; ALVES, Sirlene Siqueira. **Logística e sustentabilidade: as vantagens da fabricação de tijolos ecológicos.** Monumenta, Paraíso do Norte, PR, v. 1, n. 1, p. 84-93, 2020.
10. CAMPELO, N.S.; SEYE, O.; SANTOS, E.C.S.; HORBE, AA.M.C.; ROCHA, F.S.; ARAGÃO, A.F.; PINHEIRO, S.C.; CABRAL, E.M. **Ensaios tecnológicos em cerâmica vermelha do polo oleiro dos municípios de Iranduba e Manacapuru – AM.** Anais do 48º Congresso Brasileiro de cerâmica. 2004.
11. CAMPOS, Alessandro; NASCIMENTO JUNIOR, João Batista do; BRITO, Larissa Tessari. **Comportamento estrutural de tijolos de solo-cimento utilizando diferentes fontes de água e métodos de cura.** Interações, V. 20, N. 1, pp. 283-296, 2019.
12. CHAZDON, R. L. **Regeneração de florestas tropicais.** Bol. Mus. Para. Emílio Goeldi. *Cienc. Nat.*, v. 7, n. 3, p. 195-218, 2012.
13. CLIFT, Roland e DRUCKMAN, Angela. **Taking Stock of Industrial Ecology**. 1. Ed. Guildford: Springer open, 2016. https://doi.org/10.1007/978-3-319-20571-7
14. DATCHEFSKI, Edwin. **The total beauty of sustainable products.** Ed. RotoVision, 2001.
15. EMF – ELLEN MACARTHUR FOUNDATION. **Towards the Circular Economy – Vol. 1: Economic and Business Rationale for a Circular Economy.** Cowes: Ellen Macarthur Foundation, 2012.
16. FERREIRA, Débora Macanjo; LUSO, Eduarda; CRUZ, Maria Lurdes; MESQUITA, Luís M.R.; GONTIJ, Guilherme. **Fire behaviour of ecological soil–cement blocks with waste incorporation: Experimental and numerical analysis**. Journal of Fire Sciences. Vol 38, Issue 2, 2020.
17. FERREIRA, Débora; LUSO, Eduarda; CRUZ, Maria. **Blocos ecológicos de solo-cimento com incorporação de resíduos.** Construction Pathology, Rehabilitation Technology and Heritage Management. 7th REHABEND Congress. Caceres, Spain. Maio, 2018.
18. FOSTER, Allan; ROBERTO, Samanta Souza; IGARI, Alexandre Toshiro. **Economia circular e resíduos sólidos: uma revisão sistemática sobre a**

eficiência ambiental e econômica. Encontro Internacional sobre Gestão Empresarial e Meio Ambiente. 2016.

19. FRANÇA, Bruno Rangel; AZEVEDO, Afonso Rangel Garcez; MONTEIRO, Sergio Neves; GARCIA FILHO, Fabio GRANDE, Fernando Mazzeo da Costa; MARVILA, Markssuel Teixeira; ALEXANDRE, Jonas; ZANELATO, Euzébio Bernabé. **Durability of Soil-Cement Blocks with the Incorporation of Limestone Residues from the Processing of Marble.** Materials Research. Paper e20171118, 2018a.
20. França, Danilo de Araújo; Simões, Marina Teixeira; Gomes, Kíria Nery Alves do Espírito Santo. **Tijolo Solo-Cimento: Processo produtivo e suas vantagens econômicas e ambientais.** Revista Científica de Engenharia Civil, v 01. N. 01, 144-155, 2018b.
21. FUNDI, Sanewu Isaac; KALULI, J.W.; KINUTHIA, J. **Performance of interlocking laterite soil block walls under static loading.** Construction and Building Materials. Volume 171, Pages 75-82, 2018. https://doi.org/10.1016/j.conbuildmat.2018.03.115.
22. GARCEZ, Lilyanne Rocha e LEITE, Hosana Emília Sarmento Costa. **Ceramic composite reinforced with agroindustrial waste.** European Academic Research. Vol. VIII, Issue 3, pp 1660 a 1678, 2020.
23. HAWKEN, Paul; LOVINS, Amory e LOVINS, L.H. **Capitalismo Natural**: criando a próxima revolução industrial. 1^a. Ed., São Paulo: Cultrix, 2000.
24. HERMANN, A.; LANGARO, E. A.; KLEIN, N. S. **Particle packing of cement and silica fume in pastes using an analytical model.** Revista IBRACON de Estruturas e Materiais, v. 9, n. 1, p. 48-65, 2016.
25. HUMMELS, Harry e ARGYROU, Aikaterini. **Planetary demands: Redefining sustainable development and sustainable entrepreneurship.** Journal of Cleaner Production. Vol. 278, paper: 123804, 2021.
26. IBGE – Instituto Brasileiro de Geografia e Estatística. **Pesquisa Nacional por Amostra de Domicílios – Censo Demográfico – Projeção.** 2020.
27. IMAM, A.; SRIVASTAVA, V. **Review study towards effect of Silica Fume on the fresh and hardened properties of concrete.** Advances in Concrete Construction, v. 6, n. 2, p. 145-157, 2018
28. KONGKAJUN, Nuntaporn; LAITILA, Edward A.; INEURE, Pitcharat; PRAKAYPAN, Wichit; CHERDHIRUNKORN, Benya; CHAKARTNARODOM, Parinya. **Soil-cement bricks produced from local clay brick waste andsoft sludge from fiber cement production.** Case Studies in Construction Materials. Vol. 13, paper: e00448, 2020.
29. LEONEL, R. F.; FOLGUERAS, M. V.; DALLA VALENTINA, L. V. O.; PRIM, S. R.; PRATES, G. A.; CARASCHI, J. C. **Characterization of soil-cement bricks with incorporation of used foundry sand. Revista** Cerâmica, Vol. 63 pp. 329-335, 2017. http://dx.doi.org/10.1590/0366-69132017633672131.
30. LIMA, Viviana Mendes; COSTA, Sandra Maria Fonseca da; RIBEIRO, Helena. **A contribution from the DPSIR methodology to the study of a small town in the Amazon: Ponta de Pedras, Pará, Brazil.** Saúde Soc. São Paulo, v.26, n.4, p.1071-1086, 2017. DOI 10.1590/S0104-12902017170861

31. LÔBO, Josefa Missiliene Cordeiro; FERNANDES, Renato de Oliveira; MORAIS, João Marcos Pereira de; BARBOZA, Eliezio Nascimento; SILVA, Eduarda Morais da. **Market analysis of soil-cement ecological brick in the Cariri Metropolitan Region.** Research, Society and Development, v. 9, n.8, e180984966, 2020.
32. MACIEL, Cleiton Ferreira. **Homens do Barro" e Estratégias Empresariais: um estudo da relação capital-trabalho no Pólo oleiro-cerâmico da Região Metropolitana de Manaus-AM.** Programa de Pós-Graduação em Sociologia da Universidade Federal do Amazonas. Dissertação de mestrado. 2013.
33. MACHADO, André Luiz; SCHNEIDER, Roselene Maria; AMARAL, Adriana Garcia do; ARRUDA, Rafael Soares; CRISPIM,Flávio Alessandro; OLIVEIRA, Karinna Pinheiro de; ONETTA, Jennifer de Souza; HOFFMANN, Letícia Tamara. **Soil- Cement Bricks as an Alternative for Glass Waste Disposal.** American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS). Volume 71, No 1, pp 123-135, 2020.
34. MAGALHÃES, **Cilene Farias Batista. Análise do processo produtivo dos tijolos cerâmicos na Fábrica Nova São José de Itacoatiara/AM: um estudo de caso.** Pós-Graduação em Engenharia de Processos, PPGEP/ITEC, da Universidade Federal do Pará**.** Dissertação de Mestrado. 2016.
35. MARTINS BARROS, Maiccon; OLIVEIRA, Marcelo Ferreira Leão de; RIBEIRO, Roberto Carlos da Conceição; BASTOS, Daniele Cruz; OLIVEIRA, Márcia Gomes de. **Ecological bricks from dimension stone waste and polyester resin.** Construction and Building Materials. Vol. 232, paper: 117252, 2020.
36. MORSELETTO, Piero. **Targets for a circular economy.** Resources, Conservation & Recycling. Vol. 153, paper 104553, 2020.
37. NEGREIROS, Ronan de Souza; PESSOA JUNIOR, Erasmo Sergio Ferreira; SOUZA, Wamber Broni de; JUSTI, Jadson; NEGREIROS, Ronei de Souza; RAMOS, Juliano Carneiro; SILVA, Adensilzon Nunes da. **Mineralogical characterization of black earth from the Marajó and Gregostone communities, in Parintins, Amazonas.** Braz. Ap. Sci. Rev, Curitiba, v. 4, n. 5, p.2882-2894 set./out. 2020.
38. PAULI, G. **The blue economy: 10 Years, 100 Innovations, 100 Million Jobs.** Taos: Paradigm Publications, 2010.
39. OTI, J.E. e KINUTHIA, J.M. **Stabilised unfired clay bricks for environmental and sustainable use.** Applied Clay Science, Nº 58, pp. 52–59, 2012.
40. PEREIRA, Eusinia Louzada; SANTOS, Vívian Silva dos; JORGE, Wladimir Poletti. **Red ceramics industry: analysis of accidents in the state of Rio de Janeiro from 2012 to 2017.** Brazilian Journal of Development, Curitiba, v.7, n.2, p. 19350-19360 feb. 2021.
41. POORVEEKAN, K.; ATH, K.M.S.; ANBURUVEL, A.; SATHIPARAN, N. **Investigation of the engineering properties of cementless stabilized earth blocks with alkali-activated eggshell and rice husk ash as a binder.** Construction and Building Materials, Nº 277, paper 122371, 2021.

42. PRIYADARSHINI, Priya e ABHILASH, Purushothaman Chirakkuzhyil. **Circular economy practices within energy and waste management sectors of India: A meta-analysis.** Bioresource Technology. Vol. 304, paper: 123018, 2020.
43. ROQUETE, José Guilherme. **Repair of environmental damages caused by deforestation in the Amazonia: a methodological proposal.** Revista Direito Ambiental e sociedade, v. 9, n. 3, p. 137-166, 2019.
44. SASUI, Huwaja; WATCHARIN, Jinwuth and SIRIMAS, Hengrasmee. **The Effects of Raw Rice Husk and Rice Husk Ash on the Strength and Durability of Adobe Bricks.** Civil Engineering Journal. Vol. 4, No. 4, 2018. http://dx.doi.org/10.28991/cej-0309128
45. SCHOR, Tatiana; OLIVEIRA, José Aldemir de; MORAES, André de Oliveira; SANTANA, Paola Verri de. **Apontamentos metodológicos sobre o estudo de cidades e de rede**
46. **urbana no Estado do Amazonas, Brasil.** PRACS: Revista Eletrônica de Humanidades do Curso de Ciências Sociais da UNIFAP. Macapá, v. 9, n. 1, p. 09-35, jan./jun. 2016. DOI: 10.18468/pracs.2016v9n1.p09-35
47. SEGANTINI, Antônio Anderson da Silva e WADA, Patrycia Hanna. **Estudo de dosagem de tijolos de solo-cimento com adição de resíduos de construção e demolição.** Maringá, V. 33, N. 2, pp. 179-183, 2011.
48. SHAFIQ, N.; NURUDDIN, M. F.; ELHAMEED, A. A. **Effect of Sugar Cane Bagasse Ash (SCBA) on Sulphate Resistance of Concrete.** International Journal of Enhanced Research in Science Technology & Engineering. Vol. 3, pp. 64-67, 2014.
49. STAHEL, Walter R. **The Performance Economy**. 2. Ed. London: Palgrave Macmillan, 2010.
50. TEIXEIRA, Felipe Pinheiro; MACHADO, Thaís Guedes; JESUS JUNIOR, Neilton Paixão de; BORGES, Simone Pereira Taguchi; RIBEIRO, Rosinei Batista; BORGES JÚNIOR, Luiz Antônio. **Technological properties of soil-cement brick with 2 holes.** Tecnol Metal Mater Min. 2021;18:e2147 | https://doi.org/10.4322/2176-1523.20212147
51. UNEP – *United Nations Environmental Programme – Sustainable Biuldings And Climate Iniciative*. Common **Carbon Metric for Measuring Energy Use and Reporting Greenhouse Gas Emission from Building Operations**, 2012.