Sustainability and Environmental Awareness in the Ceramic Industry – Product Development and Life Cycle Approaches for Glazed Tiles

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Abstract—The choice of building materials is primarily based on technical, economic and aesthetic aspects, but environmental impact cannot be ignored. The objective of this research was to assess the factors in the product development aiming to improve slipperiness of ceramic tile. Firing time and temperature representing 8 manufacturing scenarios were examined taking into account the change in glazing. Laboratory slip resistance and surface roughness tests were conducted. While optimizing surface properties, environmental performance of ceramic tile was investigated with the analysis of Environmental Product Declarations (EPD) focusing on manufacturing and maintenance of its life cycle. This methodology supports manufacturers to follow sustainability and to optimize design decisions. Referring to the Life Cycle Assessment of a building, the effect of a complex correlation system reveals a combination of technical, economic and environmental assessment.

Index Terms—Ceramic Tile, Slip Resistance, Life Cycle Assessment, Sustainability.

I. INTRODUCTION

Building materials represent an important research area for sustainable construction. For this reason, not only technical and aesthetic aspects shall be taken into account, but it is essential to know the environmental impact of these materials, which has a decisive part in the eco-design and construction of an environmentally friendly building. This topic is well explored in the literature, so articles closely related [1-6] also confirm, that these decisions have effects for the whole lifespan of the building, e.g. energy costs, recycling and waste generation also.

Due to growing concerns, industries are paying attention to environmental pollution and resource depletion as building materials play a significant role in greenhouse gas emissions (GHG) [7], so they need guidelines to facilitate and to drive the measurement and communication of the environmental behaviour of products [8]. “Roadmap for moving to a competitive low-carbon economy in 2050” was published by the EU and so, for the industrial sectors, the objective is to achieve a given amount of reduction in CO₂ emissions [9-11]. That will definitely require radical changes in the technologies. Nevertheless, increasing the share of renewable energy contributes to make production more environmentally friendly and sustainable.

For conscious design of the living space, it is essential to look for low environmental footprint solutions that can meet economic needs while providing high aesthetic quality. In addition, the choice of materials must also imply that the structures are designed to ensure safety and health. Construction works as a whole and in their separate parts must satisfy the basic requirements of the intended use for an economically reasonable working life [12]. This article focuses on safety and accessibility in use, hygiene, health and the environment, as well as sustainable use of natural resources, according to 253/1997 (XII.20.) Government Decree about the National Requirements of Building and Town Planning (OTÉK) [13].

A. Sustainability – Circular economy

The concepts of sustainability and sustainable construction are in focus for creating a healthy built environment. One of the greatest environmental impacts associated with construction is the energy use. Buildings account for up to 40% of total energy consumption (mainly from fossil fuels) and 30% of GHG emissions [14]. In addition, water use should not be neglected.

As far as sustainability is concerned improving efficiency by reducing the use of resources and fossil fuels cannot meet environmental challenges [15-16]. The linear economic model is increasingly overcome by Circular Economy (CE), which is a new approach where processes take place in a closed loop [15, 17-20]. The emergence of new product and service innovation is a benefit at various stages of optimization, while reducing the costs associated with generation and disposal of waste, as well as the associated environmental and social impacts [15, 18]. Considering circular metrics at micro and nano levels, it can be stated that every part of the value chain holds an opportunity [21].

In recent years, the need to improve sustainability performance of buildings has become a major concern for the construction industry [21]. Sustainable building strategies are based, to a certain extent, on the choice of sustainable materials that minimize the impact on the environment throughout their life cycle [22]. Sustainable construction therefore is one of the branches of sustainability that deals primarily with economic and environmental issues.

Life Cycle Assessment (LCA) is the most accepted and well established method today for environmental evaluation of construction products [1, 23-26], sustainability of materials [27], innovation and eco-design [28-31], marketing [32], and
also presenting interactions of a technological system with the environment [9, 33-36]. LCA is an internationally standardised method [21], EN ISO 14040 [37] describes the concept of product systems. There are LCA studies that identify hotspots and make proposals for improvement [22, 38-39], or suggest fundamental changes [40] to reach a certain target. Others consider that the LCA methodology is the most appropriate to assist decision-making processes in the development [35], have special focus on resource usage efficiency [22, 30, 41-42]. Many studies investigate ceramic floor and wall tiles [22, 43-44], assess environmental performance and improvement proposals [38, 45-46], define product category rules (PCR) [47], present Best Available Techniques (BAT) [39, 48] or carbon footprint [49], and make comparison with other covering material [50].

In the ceramic tile manufacturing sector, one aspect of developing an LCA model and making scenario analysis can be to discover the lines of technological development that need to be implemented in the future [9]. In order to remain competitive, the industry needs to follow a sustainable development approach in line with the 17 Sustainable Development Goals (SDGs), responding to new global challenges such as resilience, smart cities and new architecture, sustainable production and consumption, and climate change [51].

B. Ceramic industry

The word ‘ceramic’ has the meaning of a product, fired on high temperature and made from inorganic (mainly silicate) raw materials, that plays a vital role in our lives from even construction materials to consumer products [52]. More specifically ceramic tiles according to the harmonized standard EN 14411 [53] are widely used floor coverings. The manufacturing technology has been gradually transformed into an almost fully automated fast-firing technique, in the direction of serial production, increasing productivity, reducing costs and changing functional requirements. Difference in surface texture can be achieved by glazing, so the vitrified cover gives the ceramic tile a series of technical and aesthetic features including colour and gloss [54].

Ceramic tiles require special attention in terms of sustainable construction, as the production consumes significant amounts of natural resources and energy from raw material extraction and preparation through production and transportation processes [10, 48, 55-57]. Thermal energy is the most important demand that is mainly obtained by combustion of natural gas, which represents 90% of the overall direct energy consumption. Process stages responsible for thermal energy consumption are spray drying of ceramic slurries (36%), drying of the formed ceramic tile bodies (9%), and ceramic tile firing (55%) [9, 56, 58].

Ceramic industry faces many challenges in the next period in order to reconcile the achievement of climate policy goals with retaining and with increasing production and more efficient, cost-effective work. Therefore, it is useful to identify processes with high environmental impact and production stages. Strategic decisions are needed to comply with future environmental standards [7]. The roadmap of the European ceramic industry considers alternative energy sources, as well as current and future production technologies [59]. It also urges to look at the complete life cycle, because the contribution to resource and energy efficiency can only be acknowledged with a holistic approach, regarding durability and impact over the use phase [9] with regard to provide environmentally friendly solutions. Due to the competition in the ceramic tile manufacturing, beyond minimizing costs, factories use their innovative capacity to increase the environmental quality of products [60], to open up new market segments [15] and to meet the requirements of sustainable construction from the durability point of view also.

II. MATERIAL

The scope of this article is the product development of the biggest Hungarian ceramic tile producer improving slipping properties of its product belonging to the water absorption group of B1a (Ew ≤ 0.5 m%). In the research 8 different types of dry-pressed glazed samples represent 8 manufacturing scenarios. Fig. 1 shows the microscopic view of the surfaces. Numbering of the samples represents different glazing applications deriving from consecutive experiments [61]. The composition of raw materials was accepted as non-variable parameter. In the product design, two major factors were considered: enhancing slip-resistant ability of the tile and optimizing the surface texture.

Table 1 summarizes the manufacturing parameters (firing time and temperature) along with the different glazing operation and decoration application. From sample 1 to 4, glaze types were the same, there were changes only in firing time and temperature. Engobe and glaze were applied separately on the surfaces. For the second group of 4 different tiles, firing time and temperature remained almost the same, but there were changes in glazes.

| Sample | Firing time (min) | Temperature (°C) | Glaze type | Glazing operation |
|--------|------------------|-----------------|------------|-------------------|
| Sample 1 | 48 | 1180 | Glaze-A | engobe and glaze applied separately |
| Sample 2 | 49 | 1200 | | |
| Sample 3 | 50 | 1190 | Glaze-B | |
| Sample 4 | 50 | 1175 | Glaze-C | |
| Sample 5 | 50 | 1195 | Glaze-D | |
| Sample 6 | 50 | 1190 | Glaze-D* | |
| Sample 7 | 50 | 1195 | | |
| Sample 8 | 50 | 1195 | | |
III. METHODS

Based on the concept of the technical development, firing time and temperature were recorded. Tiles were tested in the laboratory in order to assess slip-resistant ability and to indicate the variation in surface roughness while optimizing firing process and glazing. Environmental performance and impacts of the product were examined with the analysis of EPDs focusing on 2 stages of the life cycle.

A. Laboratory tests

CEN/TS 16165 [62] technical specification contains 4 different test methods (Barefoot Ramp test, Shod Ramp test, Pendulum friction test and Tribometer test) for determining slip resistance of pedestrian surfaces. In this study pendulum tester (Skid-resistance tester) was chosen, because it can provide results on a wide scale (from 0 to 150 at intervals of 5 units) while the slider assembly moves across the test surface. The measure of the energy loss represents the friction between slider and test surface. This value is called the Pendulum Test Value (PTV). Larger PTV means a better slip-resistant ability of the surface.

Surface roughness was significant due to the fact that production technology defines the surface quality of a flooring material. The detected vertical deviations of a real surface from its ideal form represent unevenness of the samples. Measurements were performed by Surftest SJ-301 surface roughness-meter according to EN ISO 4288 [63]. This device is a stylus type measuring instrument developed for portable use. It detects the texture of samples and quantifies the surface topography. Results can be displayed digitally and graphically. Ra arithmetical mean deviation represents the smoothness of surface. Rz maximum height of the assessed profile illustrates the difference between peaks and valleys.

B. Environmental evaluation

EPD is a possible communication tool, since it represents a set of environmental indicators based on the application of the LCA methodology [8, 64]. The steps for generating an EPD are clearly set out. For ceramic tiles EN 17160 [65] is essentially the PCR. It provides guidelines taking into account EN 15804 [66] for Type III environmental declarations, so life cycle stages are subdivided into the modules A1–A3 (Product stage), A4–A5 (Construction process stage), B1-B7 (Use stage), C1–C4 (End-of-life stage) and module D (Benefits and loads beyond the system boundary).

EPD gives verified environmental profile and its use has been spreading recently and widely in the construction sector abroad [8, 21, 67]. Besides, in Hungary, there is still lack of knowledge about EPD by consumers. Nevertheless, it can provide basic and valuable information as seen in various cases [1, 68-70], so a compilation of EPDs was used to support the assessment of sustainability and potential impact for the environmental evaluation.

IV. RESULTS

A. Laboratory tests results

Assessing slipping properties of ceramic tiles is still challenging in Hungary. There is no requirement in EN 14411 [53] that architects can follow to design slip-resistant flooring. On the one hand surface properties are essential in meeting the requirements of safety in use. To ensure sufficient slip resistance to protect against the risk of falling, tiles intended to use on floors need to be tested [71]. On the other hand, there is a remarkable risk of slipping due to interaction with slippery materials. Therefore establishing an effective cleaning is significant taking into account surface roughness, as a contributor to slip resistance. Evaluation of slipperiness needs a complex understanding of the affecting factors. Results of a previous article [72] show how the cleaning regime effected the change in slipperiness and roughness of ceramic tiles. Deterioration in the surface can influence the quality, which is definitely related to firing and glazing.

Table II contains the measured values of slip resistance and surface roughness. PTV is the average of 5 measurements carried out on 5 samples from each type of tile. The average values of Ra and Rz were determined on 10 different locations of 5 samples of the different types of tiles.

![Fig. 2. Relationship between firing time and temperature of consecutive experiment stages.](http://dx.doi.org/10.24018/ejers.2020.5.8.2027)
With the same analogy, Fig. 4 represents the parameters of surface roughness, thus the variation in surface structure due to the difference in firing and glazing.

Production technology determines the surface quality of a ceramic tile. Measuring roughness parameters and evaluating diversity in the characteristics of the surface is a practical approach to understand the influence of manufacture and the future effect on abrasion and friction.

Scatter plot of arithmetical mean deviation (Ra) and maximum height of the assessed profile (Rz) measured on the glazed surfaces illustrates the connection between these parameters (Fig. 5). Based on the results of Ra and Rz determined on the surface of the glazed ceramic tile samples, it can be shown that the values of Ra and Rz are closely correlated ($R^2 = 0.98$).

Detecting unevenness of the surface is an approach to measure and analyse the texture, likewise it is important in the assessment of slip resistance. Risk of slipping is mostly affected by the presence of water, a possible contamination on floors. Therefore, quantification of the decrease in PTV due to wetting the surface (Fig. 6.) is another aspect to verify the significance of understanding surface characteristics of ceramic tiles.

The greater the surface roughness of the tested sample, the lower the decrease in PTV after wetting the surface. This is experienced in both cases represented in Fig. 7, where related roughness parameters are arranged in descending order based on the corresponding decrease in PTV. However, measurements of the sample 5. show alteration, so it needs further investigation.

Fig. 7 clearly indicates that the variation in surface texture, as a result of the difference in firing and glazing operation, can influence slip-resistant ability. It is especially crucial in the presence of a contaminant. Distribution of results measured on particular glazed surfaces can support this theory. As previous studies showed [71, 73] in order to understand the behaviour of a ceramic tile, its surface structure needs to be measured. So quantification of slipperiness and surface roughness indicates an aspect with which clea

ability can be interpretable, due to the fact that all three are interrelated properties of the flooring. Based on the results and the assumptions of previous research, Ceramic Floor Slipperiness Classification (CFSC) was compiled concerning the selection and application of ceramic tiles [71].

As for the intended use, selecting the most appropriate
product is not the only task what needs to be considered. Characteristics of the surface, for example slipperiness, are likely to change with use. In order to perform technical and aesthetic functions, ceramic tiles, as the surface finish of the flooring, need to be kept in perfect condition. These products usually have sufficient slip resistance when clean and dry, but habits and circumstances determine the frequency and the effectiveness of cleaning [1, 71, 74-75]. As long as the required or specified slip resistance depends on the maintenance by frequent effective cleaning with appropriate detergent and tools, life cycle approach to identify environmental impact has a great value in examining and understanding the behaviour of ceramic tiles and the surfaces. Furthermore, it can reveal possible alternatives for the technology changes that are likely to be implemented in the future.

B. Data analysis of EPDs

This article was built on a comprehensive review of EPDs. These multi-page documents have an important role to collect information about manufacturing parameters (firing time and temperature) as well as the impact of cleaning regimes during maintenance. As mentioned in [65] impact categories are the same that need to be declared, and without a thorough understanding of the described life cycle, it is difficult to compare products.

This research focuses on circumstances of European factories, so primarily EPDs of the major Italian and Spanish plants were collected. These countries are the largest EU ceramic tile producers, but German, Czech and also Turkish factories, so primarily EPDs of ceramic tile manufacturers were taken into account to get a wider scope. Although EPDs are publicly available and can be downloaded from Programme operators’ database, in Table III manufacturers were not identified, only the country of the factory is given. In all cases, the functional unit was 1 m² of ceramic tile for a period of 50 years.

| ID. | Country of the factory | Programme operator | Software | Scope of EPD |
|-----|------------------------|--------------------|----------|--------------|
| EPD1 | Italy                  | IBU                | GaBi     | group of companies and plants |
| EPD2 | Germany                | IBU                | GaBi     | group of companies and plants |
| EPD3 |                       |                    | GaBi     | one plant    |
| EPD4 |                       |                    | GaBi     | one plant    |
| EPD5 | Spain                  | DAPcontrol        | ND*      | one plant    |
| EPD6 |                       |                    | GaBi     | one plant    |
| EPD7 |                       |                    | GaBi     | one plant    |
| EPD8 |                       |                    | GaBi     | group of plants |
| EPD9 | Italy                  | EPDItaly          | GaBi     | one plant    |
| EPD10|                       |                    | GaBi     | one plant    |
| EPD11|                       |                    | GaBi     | one plant    |
| EPD12|                       |                    | GaBi     | one plant    |
| EPD13|                       |                    | GaBi     | one plant    |
| EPD14|                       |                    | GaBi     | one plant    |
| EPD15|                       |                    | GaBi     | one plant    |
| EPD16|                       |                    | GaBi     | one plant    |
| EPD17|                       |                    | GaBi     | one plant    |
| EPD18|                       |                    | GaBi     | one plant    |
| EPD19|                       |                    | GaBi     | one plant    |
| EPD20|                       |                    | GaBi     | one plant    |
| EPD21|                       |                    | GaBi     | one plant    |
| EPD22|                       |                    | GaBi     | one plant    |
| EPD23| Czech Republic         | SimaPro           | group of plants |
| EPD24|                       |                    | SimaPro  | group of plants |
| EPD25|                       |                    | SimaPro  | group of plants |
| EPD26|                       |                    | SimaPro  | one plant    |
| EPD27| Turkey                | International 1EPD | SimaPro  | group of plants |
| EPD28|                       |                    | SimaPro  | group of plants |
| EPD29| Spain                 | GlobalEPD         | SimaPro  | group of plants |
| EPD30|                       |                    | SimaPro  | group of plants |

However, the EPD system boundaries follow the modular approach outlined in the EN 15804 [66], in this research 2 declared modules (A1-3 and B2) were chosen to be investigated in more details.

A1-3, Product stage

In most EPDs modules A1 to A3 are declared as one aggregated module A1-3. This stage describes those processes that provide the material and energy inputs into the system, and the following manufacturing and transport processes up to the factory gate, as well as the processing of any waste arising from those processes. Previous studies indicated that the manufacturing process accounts for more than 40% of almost all impact type [22]. One of its key stages that exerts the dominant effect on the environment is the firing. According to current technology, firing of the ceramic tiles occurs at a temperature of 1000-1250 °C; in order for the product to gain its mechanical and aesthetic properties [76], based on the physical and chemical reactions that take place in the ceramic composition during thermal treatment in the kiln [10]. According to [65] manufacturing part in EPDs does not require to specify firing parameters. Even so in some cases firing time (20%) and/or temperature (63%) of different manufacturing plants were provided (Table IV) with the corresponding water absorption group and average weight per m² of the product.

| ID. | water absorption | average weight/m² | firing time | firing temperature |
|-----|------------------|-------------------|-------------|--------------------|
| EPD1 | all              | 19.90             | 1000-1300 °C| ND*                |
| EPD2 | Bla, BlII        | 18.63             | ND*         | ND*                |
| EPD3 | Bla              | ND*               | ND*         | ND*                |
| EPD4 | Bla, Blb         | 23.32             | ND*         | ND*                |
| EPD5 | Bla, Blb         | 23.88             | ND*         | ND*                |
| EPD6 | Bla              | 21.81             | ND*         | ND*                |
| EPD7 | Bla, Blb         | 22.39             | ND*         | ND*                |
| EPD8 | Bla, Blb, Blb, Blb | ND*                  | ND*         | ND*                |
| EPD9 | Bla              | 21.05             | 45 min.     | 1200 °C            |
| EPD10| Bla              | 20.76             | 45 min.     | 1200 °C            |
| EPD11| Bla              | 21.05             | 45 min.     | 1200 °C            |
| EPD12| Bla              | 30.50             | up to 100 min.| 1200-1220 °C      |
| EPD13| Bla              | 25.10             | up to 100 min.| 1200-1220 °C      |
| EPD14| Bla              | 30.43             | 45 min.     | 1200 °C            |
| EPD15| Bla              | 24.80             | 45 min.     | 1000-1300 °C       |
| EPD16| Bla              | 25.50             | ND*         | 1210-1230 °C       |
| EPD17| Bla              | 24.40             | ND*         | 1000-1300 °C       |

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During the firing process a great quantity of thermal energy (namely 50% of all thermal energy consumption) is obtained mainly from natural gas combustion. Due to the high temperatures, big amount of natural gas is required and consequently, there is a greater amount of air emission (CO\textsubscript{2}, etc.), which contributes to Global Warming Potential (GWP).

In fact, according to data reported by [22] lowering the maximum firing temperature from 1200-1225 °C to 1100 °C can lead to approx. 20% reduction in energy consumption.

As a matter of fact, adjustment in the glaze composition is required when lowering peak firing temperatures or shortening firing cycles, that assumes high-level competence in the influence of different raw materials and in the behaviour of the glaze [77]. In the investigated EPDs description of glazing operation contains general information. None of them specifies the glaze type, only the components are given. Moreover the nature of the ceramic composition also affects the firing operation (peak temperature, cycle duration, etc.), thus influences the thermal energy consumption. Two third of the EPDs contains the composition of raw materials as a percentage, the rest only identifies those.

Without doubt, it was a general aim already twenty years ago to reduce firing time, to achieve and maintain a constant uniform temperature at all points in a given cross-section of the kiln, as well as to minimize energy losses. It reveals that present improvements, such as the recovery of excess heat from kilns, heating curve optimization and additional equipment to decrease emissions to air are key elements in reducing environmental burdens. According to a study [78], 100 °C reduction in peak firing temperature would only mean 6.5% modification in consumption. Although certain energy saving measures are being implemented in single-deck kilns, a significantly lower energy consumption would emerge in the long-term.

The main technologies are almost similar in European factories, they apply dry-pressing and single-firing in roller kilns using natural gas, so the Hungarian manufacturer operates the same technique with the same type of machinery. Flowchart of this single-firing process is shown in Fig. 8.

| EPD | Glaze Type | Maximum Firing Temperature |
|-----|------------|-----------------------------|
| EPD18 | Bla         | 24.30 ND*                   |
| EPD19 | Bla         | 19.30 ND*                   |
| EPD20 | Bla         | 25.60 ND*                   |
| EPD21 | Bla         | 21.50 ND*                   |
| EPD22 | Bla         | 16.30 ND*                   |
| EPD23 | Bla         | ND* 1000-1300 °C            |
| EPD24 | Blb         | 17.30 ND*                   |
| EPD25 | Bla         | 22.00 ND*                   |
| EPD26 | Bla         | 19.42 ND*                   |
| EPD27 | Bla         | 22.50 ND*                   |
| EPD28 | all         | 22.00 ND*                   |
| EPD29 | Bla         | 7.86 ND*                    |
| EPD30 | Bla         | 20.30 ND*                   |

Not only kiln operation conditions and electricity consumption are key elements that justify the variability in impacts. Transportation of the raw and ancillary materials is another process that could explain the environmental differences [22]. In this case one of the great advantages of the Hungarian factory is owning a clay mine, where high-quality clay is extracted. It is located close to the plant, so the company saves significant transportation costs.

The highlight is on climate change and global warming. The indicator for this environmental impact, GWP quantifies the total amount of GHG emissions associated with the analysed system and expressed as kg equivalent carbon dioxide (CO\textsubscript{2}-eq.). It represents the CO\textsubscript{2} emissions produced mostly in the combustion and extraction of natural gas during the manufacturing process. Even though the energy mix of the country cannot be controlled by the manufacturer, improvement in factories is meant to reduce energy consumption during this phase [8].

The manufacturing phase is also responsible for a significant contribution to the depletion of abiotic resources because of the consumption of raw materials and non-renewable fuels, as well as to the acidification due to the emission of acid compounds during manufacture.

B2. Maintenance

In the use stage related to the building fabric, maintenance (B2) was further investigated. In general, the maintenance of a building includes activities for the correct functioning, the repair of damages, the cleaning of the building, and the management of utility consumption costs [79-80]. This section in the EPD covers actions planned to maintain the installed ceramic tile during the service life in order to keep its required functional and technical performance, and to preserve the aesthetic qualities. Cleaning is a preventative and regular activity that differs so significantly from other maintenance actions. In fact, the size and function of the room along with the type of the covering can determine cleaning regime and peculiarities of the tasks. A single space is cleaned with several different periodicities.

Admitting that safety is closely related to durability, conditions to which the tiled surface will be exposed after fixing shall be taken into consideration. EPDs were consulted to specify the cleaning operations and their frequencies as a function of the described scenarios for residential use. Table V shows a variety of cleaning indicating the different combination of water and detergent consumptions.
TABLE V: LIST OF CLEANING METHODS DESCRIBED IN THE STUDIED EPDS

| ID  | Description of the cleaning process for residential use |
|-----|--------------------------------------------------------|
| EPD1| 0.3 ml of detergent and 0.002 l of water to wash 1 m² |
| EPD2| 0.0003 kg of cleaning agent and 0.000002 m³ water    |
| EPD3| 0.03 kg of detergent and 5 l of water to wash 50 m²  |
| EPD4| 0.11 l water / m², 0.134 ml detergent / m²             |
| EPD5| 0.03 kg of detergent and 5 l of water to wash 50 m²  |
| EPD6| Water = 0.1 kg / wash, Detergent = 0.0006 kg / wash    |
| EPD7| 0.03 kg of detergent and 5 l of water to wash 50 m²  |
| EPD8| 0.11 water / m², 0.134 ml detergent / m²              |
| EPD9|                                                        |
| EPD10|                                                      |
| EPD11|                                                      |
| EPD12| 0.2 ml of detergent and 0.1 l of water to wash 1 m²   |
| EPD13|                                                        |
| EPD14|                                                        |
| EPD15|                                                        |
| EPD16| 0.3 ml of detergent and 0.002 l of water to wash 1 m² |
| EPD17|                                                        |
| EPD18|                                                        |
| EPD19| 0.2 ml of detergent and 0.1 l of water to wash 1 m²   |
| EPD20|                                                        |
| EPD21|                                                        |
| EPD22|                                                        |
| EPD23| 0.3 ml detergent and 0.002 l water to wash 1 m²       |
| EPD24|                                                        |
| EPD25|                                                        |
| EPD26| 0.2 ml detergent and 0.1 l water use to wash 1 m²     |
| EPD27|                                                        |
| EPD28|                                                        |
| EPD29|                                                        |
| EPD30| 0.11 water/ m² and 0.134 ml detergent/ m²              |

According to the scenarios described in Table V, the cleaning is predicted to occur similarly once a week, which represents the lowest class in the CFSC system [71]. In this case the weakest slip-resistant ceramic floor with pedestrian use is assumed on which little or without scratching dirt is removable manually. However, the frequency and regime differ in reality and ceramic tiles having a high value of slip resistance are in focus. In residential houses, for example ceramic tiles in bathrooms and kitchen or even on the terraces suffer average degree of wear with significant amounts of scratching dirt, so occasional (2–5×/week) cleaning is required in order to reduce the risk of slipping. With the application of this classification system, threshold levels of CFSC indicate an acceptable cleaning regime in relation to an intended use characterized by wear/traffic and contamination also.

Nevertheless, the scenario shall be more complex for commercial or industrial usage that involves a treatment with more regulated frequency and intensity. In order to cope with this fact, cleaning operation, that now includes the amount of water and cleaning agent according to [64], shall be completed with the electricity consumptions of equipment. Depending on the degree of wear, that is how much the surface is exposed to the specified stresses, use conditions could be determined, moreover the total maintenance costs of the whole building could be predicted better. As far as slip or fall accidents are concerned, facility management shall not neglect appropriate cleaning regime, that is providing adequate slip resistance and proper functioning in buildings instead of preferring cost saving.

During the service life, which is 50 years for a ceramic covering, it shall be cleaned regularly to a certain degree depending on the type of building. So for this time period a great impact of water consumption can be assumed. In addition, cleaning due to the use of detergents implies a huge contribution to eutrophication, as it represents a relevant fraction compared to the other impact categories. The reference service life depends on the properties of the ceramic tile as well as on the in-use conditions, so a thorough knowledge of the technical and functional performance of a product is required. LCA interpretation gained from EPDs can serve as source for comparison of environmental behaviour of ceramic tiles.

V. DISCUSSION OF THE RESULTS

Today, one of the most important issues in the building stock of Hungary is the rehabilitation of residential houses. Hungarian regulation, OTÉK [13] therefore reflects the sustainability guidelines, so the aim is to create long-lasting structures and thus possess a building that can be well operated and renovated. Among the general requirements for floor coverings, not only the product characteristics but also the appropriate design and construction technology determining the use are decisive. This standpoint re-emphasizes the aspects of material choice, so following durability considerations it is worth thinking about the longest lifespan.

Considering flooring materials, no producer-specific choices are made in the beginning of the design process. Materialization, that is choosing a product from a specific manufacturer, takes place later, and usually the decision depends mainly on the technical parameters. Following the approach for improving the impact of a building, choice of a product could imply a combined assessment of more aspects. As far as safety in use is concerned, the performance for cleaning a surface is dependent on the roughness and surface quality of the ceramic tile covering. Conversely based on the results of the measured roughness parameters in a previous study [73], treatment and cleaning frequency also depend on the contamination type. Furthermore, cleanability could modify the surface and imply a change in the slip resistance of the tile. If the alteration has an impact on the surface quality, that can affect the lifetime of ceramic tile covering. For this reason, the standardized cleaning method in [65] could lead to an anomaly, thus denoting non-compliant behaviour and disadvantage of the tile.

EPD modules highlighted and investigated in this research are essential from the viewpoint of production and the building. LCA is considered to be the most suitable way to assess the environmental impacts, so this methodology could support or optimize design decisions during the early stages. Referring to the LCA of a building, the effect of this complex correlation system generates a combination of technical, economic and environmental assessment. Therefore, architects shall find the optimal solution and make well-balanced design decisions. Eco-design could be an effective methodological approach in product development in compliance with the principles of the circular economy in ceramic tile production in order to include sustainability.
along with functionality, aesthetics and quality.

VI. CONCLUSION

Ceramic tiles are popular covering material in residential houses and industrial applications also, such as food processing factories, professional and community kitchens, laboratories, storage rooms. The intended use of the tiling and therefore the environmental conditions to which it will be exposed are initial information in the designing process. The characteristics of the selected tiles are key parameters in order to carry through a tiling project properly.

Although the manufacturing process of ceramic tile entails significant consumption of energy and natural resources including water, the industry unquestionably follows the guidelines of sustainability. The use of local or relatively closely available raw materials is given priority, and certain energy saving measures are being implemented, thus resulting a significant reduction in energy consumption. The production process of ceramic tiles clearly meets the criteria in line with the circular economy. Manufacturers also make continuous improvements to reduce costs, to enhance productivity, and to map changes from functional needs in order to stay competitive.

The purpose of this article was to summarize what issues a manufacturer shall deal with during production and what aspects shall be considered in the product-design in order to meet the requirements of sustainability. Although the target of the experimental development is to improve certain technical parameters, the impact of production on the environment cannot be ignored. In addition, it is also necessary to examine the role of the ceramic tile as a product in association with the building and what significance it has during the lifespan.

Raising awareness in technological trends to fulfil the required targets, and following sustainability in order to reduce the environmental impact are not only social, but economic objectives of the construction sector. In order to achieve quality in built environment, it is essential that construction works are carried out for a common goal and on the basis of uniform guidelines. In addition, it is recommended to make the activities of the entire supply chain environmentally friendly and sustainable. The EPD of ceramic tiles, similarly to other building materials, is a powerful technical and informative tool. It allows not only professionals, but also the general public to choose products based on sustainability criteria. Therefore, manufacturers, designers and the public are jointly involved in sustainable construction and the creation of a livable built environment.

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