OPTIMIZATION OF INDUSTRIAL DESIGN PROCESSES AND MATERIAL COMPOSITION FOR SUSTAINABLE DESIGN

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ABSTRACT

Sustainable product development has become one of the central challenges of modern society, requiring the integration of environmental and functional aspects throughout the entire design process. The development of distinctive and competitive sustainable industrial designs plays a significant role in high-value-added production. This paper analyzes how industrial design can contribute to product sustainability with special attention to the role of materials and composite systems in achieving a balance between mechanical performance, aesthetics, and environmental requirements. The study combines theoretical analysis with a selected case study from practice in order to identify key strategies for optimizing sustainable product development. For this purpose, the design and development of concrete washbasins were selected. Specially formulated concrete mixtures were developed to achieve an optimal balance between aesthetics, functionality and sustainability. The cast concrete provided high strength, low porosity, and a refined tactile aesthetic. The material composition was enhanced with high-quality pigments and additives, enabling control of color, texture, and surface finish. The results indicate that interdisciplinary collaboration between industrial design, materials engineering, and manufacturing processes is essential for the successful implementation of sustainable design approaches. The presented findings contribute to a broader understanding of how the integration of innovation, advanced materials, and creative design strategies can support environmentally responsible industrial design and promote sustainable innovation in product development.

Keywords: sustainability, industrial design, materials, product development, eco design.

INTRODUCTION

Industrial design is an important field of contemporary design that integrates art, engineering, technology, and user needs to develop functional, aesthetically appealing, and commercially competitive products [1,2]. Its role extends beyond shaping a product's external appearance, encompassing a comprehensive process that involves research, user needs analysis, concept development, material selection, manufacturing processes, ergonomics, functionality, and aesthetic considerations [1,3]. The successful integration of these elements enables the development of products that respond to both technological possibilities and market demands.

This paper explores the fundamental principles of industrial design through the development of a selected sanitary product - a washbasin. Particular attention is given to the relationship between form and function, material selection, manufacturing technology, ergonomics, and aesthetic requirements. The analysis also considers the role of sustainable design in contemporary product development, emphasising the importance of balancing technical performance, user expectations, and environmental considerations.

A review of existing washbasin models indicates a growing tendency towards simplified forms, the use of diverse materials, and greater opportunities for personalisation. These trends highlight the importance of considering aesthetic appearance, functionality, ergonomics, and material properties as interconnected aspects of the design process. Concrete, including microcement-based finishes, represents one of the material approaches used in contemporary washbasin design. In such products, the material serves not only as a structural component but also contributes significantly to their visual character. The availability of different colours, textures, and surface finishes allows the product to be adapted to specific interior design concepts.

The choice of concrete for the proposed washbasin is primarily motivated by its characteristic texture and distinctive sense of solidity and mass. The washbasin is conceived as a sculptural form that establishes a direct relationship with water through everyday use. The contrast between the solidity of concrete and the fluidity of water provides the conceptual basis for a restrained design characterised by clean lines and a minimalist form. This approach allows the washbasin to complement different interior styles while retaining its distinctive sculptural character.

Material selection is a key aspect of product design, as it directly influences strength, durability, weight, appearance, maintenance requirements, and manufacturing processes [4]. The materials most commonly used in commercially available washbasins include sanitary ceramics, porcelain, natural and composite stone, acrylic-based composites, microcement, and concrete. Ceramics and porcelain are widely used due to their hygienic surface properties, resistance to scratching and chemical agents, and relatively easy maintenance. Natural and composite stone offer distinctive aesthetic qualities and a sense of luxury, although their greater weight and specific maintenance requirements may present certain limitations.

The concrete selected for the proposed product is formulated with high-quality pigments and additives that allow precise control over colour, texture, and surface finish [5]. This flexibility enables the creation of individual variations, making each finished piece visually distinctive. In addition to its aesthetic potential, concrete offers several properties relevant to washbasin applications:

- Resistance to moisture, wear, and temperature variations, which contributes to its suitability for everyday use;
- Potential for environmentally responsible production, through the selection of appropriate materials and manufacturing processes aimed at reducing environmental impact;
- Distinctive appearance, resulting from natural variations in texture and colour that make each product unique.

Particular attention must be given to the surface finishing and protection of concrete [5]. Since the washbasin is regularly exposed to water, cleaning agents, and various substances, an

appropriate protective treatment is essential to prevent staining and unwanted changes in appearance. From an aesthetic perspective, the natural texture of concrete can become an integral part of the product's visual identity. The addition of pigments allows different colour shades to be achieved, while various finishing techniques can produce matte, smooth, or more pronounced textured surfaces [8].

Beyond material selection, the functional design of a washbasin requires careful consideration of its geometry and drainage system. Its internal surface must be shaped to direct water towards the drain opening and minimise water accumulation. The drain is therefore one of the key functional elements of the product. The design may also incorporate an overflow opening, which provides an additional drainage route when the basin is filled and is connected to the drainage system.

The main functional requirements of a washbasin include: Stability during use; User safety; Efficient water drainage; Prevention of excessive water splashing outside the basin; Ease of cleaning and maintenance; Resistance to moisture and commonly used cleaning agents; Secure attachment to the supporting structure.

Ergonomics is another essential consideration in washbasin design, particularly because the product is used daily and often several times throughout the day. Its dimensions and installation position should ensure a natural and comfortable user posture. The main ergonomic parameters include: Installation height of the washbasin; Width and depth of the basin; Position of the drain opening; Distance between the basin and the tap. An appropriate installation height allows users to operate the washbasin without excessive bending. If positioned too high, the basin may be uncomfortable to use, whereas an excessively low installation height can result in increased forward bending of the back. The width and depth of the basin are equally important, as they must provide sufficient space for handwashing while taking into account the available bathroom space. Consequently, the design should achieve a balance between user comfort and spatial constraints. Ergonomic considerations also include user safety. The edges of the washbasin should avoid unnecessarily sharp transitions that could pose a risk during everyday use. Rounded edges can contribute not only to a more refined appearance but also to safer and more comfortable interaction with the product.

The main design challenge addressed in this study arises from the need to integrate functional, structural, aesthetic, environmental, and manufacturing requirements within a single sanitary product. In practice, improvements in one product characteristic may adversely affect another [6, 7]. For example, increasing the amount of material may improve structural strength but also increase product weight and material consumption [8]. Similarly, more complex geometry may enhance the visual appeal of the product while complicating mould fabrication and the casting process. Material selection may also involve trade-offs between mechanical performance, aesthetic qualities, and manufacturing requirements. These interdependencies highlight the need for a comprehensive design approach in which different product requirements are considered simultaneously.

In this context, the paper investigates the application of industrial design principles, sustainable design approaches, and computer-aided design (CAD) technologies in product development. Its primary objective is to explore the development of a washbasin that responds to contemporary user needs by integrating aesthetic, functional, technical, and environmental requirements. The theoretical part examines fundamental industrial design principles, with particular emphasis on the relationship between form and function and the role of sustainable design. Consideration is also given to material selection, the rational use of resources, waste reduction, and the potential for minimising environmental impacts. The practical part focuses on the design and development of the washbasin, from initial concept definition and form development to the preparation of technical documentation and 3D modelling using CAD tools. Ergonomic, functional, and aesthetic requirements are considered throughout the design process, alongside the potential application of sustainable materials and manufacturing principles. In addition, a survey was conducted to identify the needs and attitudes of potential users, focusing on

the perceived importance of product aesthetics and functionality, material selection, and attitudes towards sustainable design. By combining theoretical considerations, survey findings, and the practical design process, the paper highlights the importance of integrating industrial design principles and sustainability considerations in contemporary product development.

MATERIALS AND METHODS

Structural development is an important stage in the product design process, as it allows the geometry, functional characteristics, and manufacturing feasibility of the product to be precisely defined. The selected product, the Qadra washbasin, was modelled using AutoCAD software, based on the principles of orthographic projection and technical drawing. The technical documentation includes the top view, front view, side view, bottom view, section A-A, and a three-dimensional (3D) representation of the product. Together, these views provide a comprehensive understanding of the product's external and internal geometry.

The colour of the product is incorporated into the material and the available colour palette is shown in Figure 1. Rather than being applied only to the surface, the pigment is distributed throughout the material. This results in consistent coloration and helps maintain the product's appearance during use (Figure 2). It also reduces the dependence of the final appearance on the condition of the outer surface.



Figure 1. Defined colour palette for the Qadra



Figure 2. The Qadra washbasin

The following functional requirements were considered during the washbasin design process: efficient and controlled water drainage; structural stability; straightforward installation and

suitability for serial production. The washbasin was designed as a compact body with a regular external contour and a centrally positioned drainage opening. The inner surface is shaped to direct water by gravity towards the central drainage point, minimizing water retention. Wall thickness is maintained consistently along the perimeter to provide mechanical strength, more uniform stress distribution, and structural stability during use. The transitions between surfaces are defined by specific radii, which help reduce stress concentrations and facilitate the manufacturing process.

The designed product has a square base with rounded edges. Its external contour is defined by precise linear segments and transition radii. The central opening for the drain fitting is positioned along the axis of symmetry, contributing to the balanced distribution of loads and the overall visual symmetry of the product. The inner volume is shaped as a recessed basin with a gentle slope towards the drainage opening. This geometry is intended to ensure the smooth flow of water and minimize its retention on the surface. The underside is designed to provide stable support and facilitate connection to the installation components.

The selected washbasin is made from specially formulated concrete mixtures developed to provide the required strength, appearance, and functional performance. Concrete offers resistance to moisture, wear, and temperature variations, while pigments and additives allow the colour and surface texture to be controlled. The manufacturing process uses locally sourced materials, with less than 5% of production waste separated for further recycling. Part of the energy demand is supplied by photovoltaic panels, while the material also offers potential for recovery and reuse at the end of the product's service life [5].

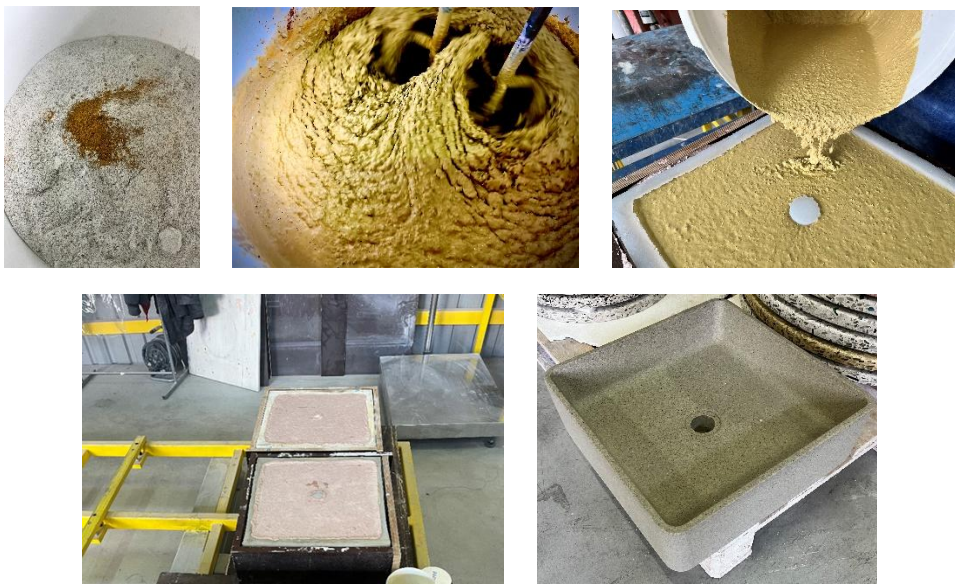


Figure 3. Qadra washbasin manufacturing process

The process begins with the preparation of a mould according to the dimensions and predefined geometry. The mould (Figure 4) must be manufactured with sufficient precision to ensure dimensional accuracy, uniform wall thickness, and the correct positioning of the drainage opening. Particular attention is given to the internal surfaces of the mould, as their finish directly affects the surface quality of the final product.



Figure 4. Mould designed for the Qadra washbasin

The technical properties of the material are an important consideration when selecting it for washbasin production. Table 1 presents the main physical, mechanical, and technical properties of the concrete, including its strength, density, resistance to water, chemicals, temperature variations, and wear, as well as its surface finish properties.

Table 1. Composition and ingredient information for cast concrete

Parameter	Value	Standard
Density (dry material)	2.200 – 2.350 kg/m^3	EN 12390-7/SRPS EN 12390-7
Compressive strength (28 days)	≥ 70 MPa	EN 12390-3/SRPS EN 12390-3
Flexural strength	≥ 12 MPa	EN 12390-5/SRPS EN 12390-5
Water absorption (sealed surface)	< 0.01%	EN 13755
Chemical resistance	Good (pH 5–10, mild chemicals)	ASTM C267
UV resistance	Slight tone variations possible	ISO 4892-2
Thermal shock resistance (uncoated)	Δ < 1 MPa (20–90 °C)	EN 14066
Frost resistance (50 cycles)	No degradation	EN 12390-9/SRPS EN 12390-9
Scratch resistance	6.5–7.5 Moh	Moh UHPC reference
Abrasion resistance	Good, depends on surface finish	EN ISO 5470-1
Thermal stability	Up to +90 °C	EN ISO 10545-8
VOC emissions (after curing)	< 0.05 mg/m³ (Low VOC)	EN ISO 16000-9 / AgBB / LEED v4
Surface finish (sealer)	Water-based, safe for skin and food contact	Food contact

The material composition is another important factor in understanding its physical, mechanical, and functional properties. Cast concrete is a composite material consisting of a cement-based binder, mineral components, pigments, and additives. The selection and proportions of these constituents influence the material's workability, strength, appearance, and suitability for the intended application (Table 2).

Table 2. Composition and ingredient information for cast concrete

Ingredient	CAS Number	EC Number	Concentration (%)	Note
Portland cement	65997-15-1	266-043-4	< 30	In powder form - irritant
Silica (SiO_2)	14808-60-7	238-878-4	30–50	Respirable crystalline fraction
Calcite ($CaCO_3$)	1317-65-3	215-279-6	10–20	Inert filler
Inorganic pigments	/	/	< 5	Fe-oxides, non-reactive
Additives (superplastic.)	/	/	< 2	PCE-based, non-reactive

*Note: The final product is in a solid, inert form. Toxicological properties and hazard classifications refer exclusively to the raw materials in their uncured or processed state.

As part of the study, a survey was conducted among potential users of the designed washbasin. The aim was to examine their attitudes towards the product's aesthetics, functionality, material origin, sustainability, ease of maintenance, and overall perception of contemporary concrete sanitary products. The survey findings were also considered in relation to the technical and design characteristics of the analysed product.

RESULTS AND DISCUSION

Technical drawing and geometric characteristics of the product

The technical drawing of the washbasin comprises several characteristic views that provide a comprehensive representation of the product. The following views and representations were prepared: top view, front view, side view, bottom view, section A-A, three-dimensional (3D) representation of the product. This set of views enables a comprehensive examination of both the external and internal geometry of the component.

The top view provides the basis for dimensioning and proportional analysis of the product. It defines the following features: overall dimensions, position and diameter of the central opening, relationship between the external and internal contours, symmetry of the design.

The main structural features of the washbasin include:

- the external and internal contours;
- wall thickness;
- transition radii;
- the central drainage opening;
- the inclination of the inner basin towards the drainage opening.

The individual views provide complementary information about the product geometry:

- Top view - illustrates the overall dimensions, drainage opening, and design symmetry (Figure 5);
- Front view - defines the height and depth of the basin (Figure 6);
- Side view - shows the product profile and overall structural height (Figure 6);
- Bottom view - indicates the position of the drainage opening and the supporting surface (Figure 5).

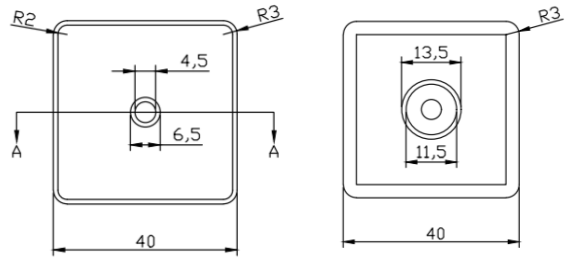


Figure 5. Top (left) and bottom (right) view

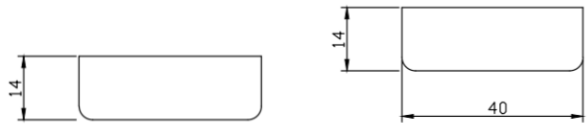


Figure 6. Front (left) and side (right) view

Section A-A represents the most important structural view, as it provides insight into the internal geometry of the washbasin. It illustrates the wall thickness, basin depth, transition radii, and inclination of the inner surface towards the drainage opening. These features are essential for understanding the product's construction and defining its geometric characteristics. The sectional view is presented in Figure 7.

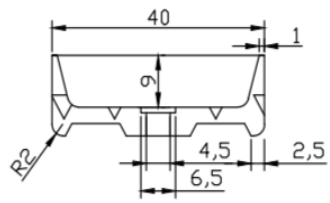


Figure 7. Section A-A

The 3D model provides an overall representation of the washbasin, illustrating its final shape, proportions, and spatial characteristics. It brings together the geometric features defined in the technical drawings, allowing the external form and the relationship between the basin contours to be clearly visualized. The model also provides a better understanding of the product's overall design and complements the technical views presented in the previous figures (Figure 8).

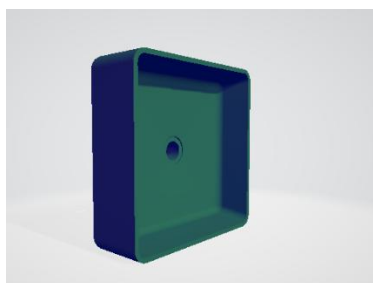


Figure 8. 3D model of the product

Sustainability aspects of the product

Sustainability is considered throughout the development and production of the Crafton washbasin, with particular attention to the selection of raw materials, efficient resource utilization, energy consumption, and the possibilities for material recovery at the end of the product's service life.

Local sourcing of raw materials: Approximately 90% of the raw materials used in production are locally sourced. These include mineral fillers and pigments. The use of locally available materials helps reduce transportation distances and supports a more sustainable supply chain [5].

Efficient material utilization: The production process achieves a material utilization rate of approximately 95%. Less than 5% of the material is separated as production waste, while the remaining material is retained within the production process. This approach reduces material losses and contributes to more efficient resource utilization [5].

Colour integrated throughout the material: Unlike surface-applied finishes, the pigment is incorporated throughout the material structure. This provides consistent coloration across the entire product and helps maintain its appearance even when the surface is exposed to regular use.

Use of renewable energy: Part of the electricity required for production is supplied by photovoltaic panels installed at the manufacturing facility. The use of solar energy helps reduce reliance on conventional electricity sources and contributes to lower environmental impacts associated with manufacturing [5].

Material recovery and reuse: At the end of its service life, the washbasin can be mechanically ground, allowing the recovered material to be considered for reuse in other applications, such as mineral filler in new panels, an additive in concrete-based materials, or secondary aggregate in architectural composites. This possibility provides an opportunity to extend material use beyond the original product.

Surface coating properties: The washbasin is finished with a protective coating designed to provide UV stability and a durable surface. The coating is also intended to meet requirements for applications involving food contact. Its VOC content is an additional environmental consideration in the selection of finishing materials [5].

Recycled packaging: The product is packaged in recycled cardboard, which provides protection during handling and transportation while reducing the need for virgin packaging materials.

Research into user attitudes and requirements in the product development process

As part of this paper, a study was conducted to identify the attitudes, needs, and expectations of potential users regarding the appearance, functionality, and properties of sanitary products, with particular emphasis on the washbasin as the subject of industrial design research. The respondents' answers were analyzed to determine which product properties users consider most important and which aesthetic and functional elements have the greatest influence on their choices. The study included questions concerning the respondents' demographic characteristics, habits, and attitudes.

The research was conducted using a survey. The questionnaire was developed in a digital format, and data were collected from potential users across different age groups. The study included respondents of different genders, ages, education levels, and employment statuses. This approach aimed to ensure a diverse sample and provide a broader understanding of their attitudes and needs. In addition to electronic data collection, some responses were collected through direct contact with respondents, using face-to-face surveys. This enabled the inclusion of respondents who use digital platforms less frequently. Following data collection, the responses were processed, and the results were presented graphically and as percentages.

The sample included respondents with a range of demographic characteristics. The variables analyzed were gender, age, education level, employment status, and monthly income. The sample included approximately equal numbers of male and female respondents (Figure 9). This distribution allows the results to be considered without a pronounced predominance of either gender.

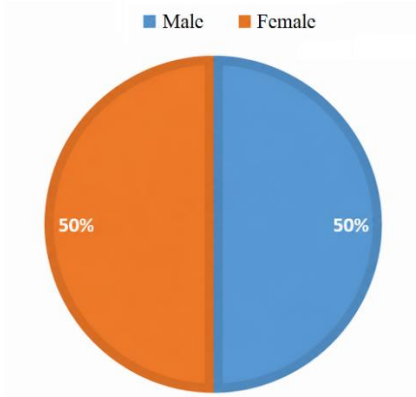


Figure 9. Distribution of respondents by gender

The age distribution shows that several age groups were represented (Figure 10). The largest number of respondents belonged to younger age groups, although older age groups were also included in the study.

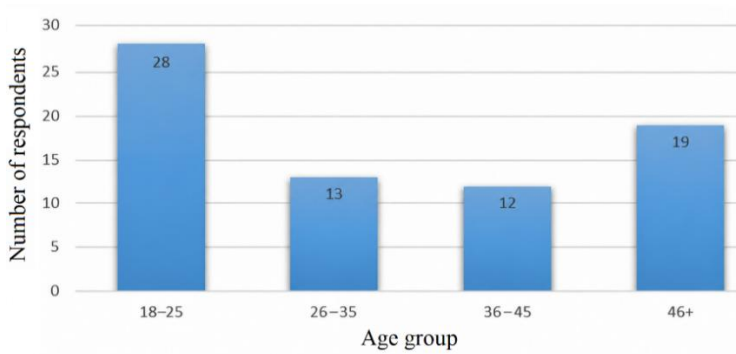


Figure 10. Age distribution of respondents

The analysis of education levels showed that respondents with different educational backgrounds were represented in the sample (Figure 11). Respondents with secondary and college or university education accounted for the largest proportions.

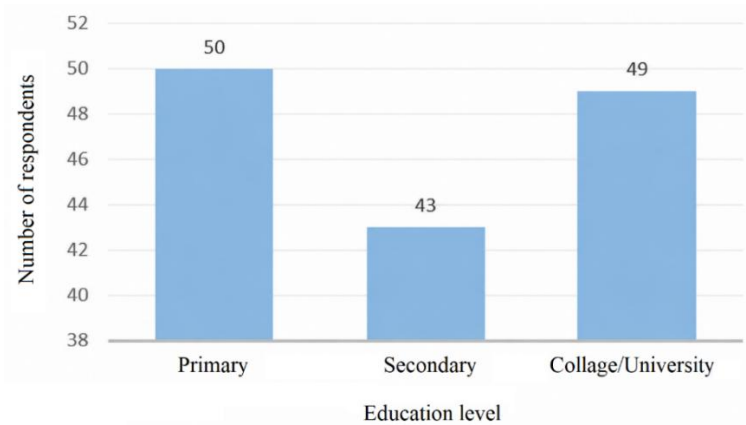


Figure 11. Distribution of respondents by education level

In terms of employment status, respondents were classified as employed, unemployed, pupils and students, or retired (Figure 12).

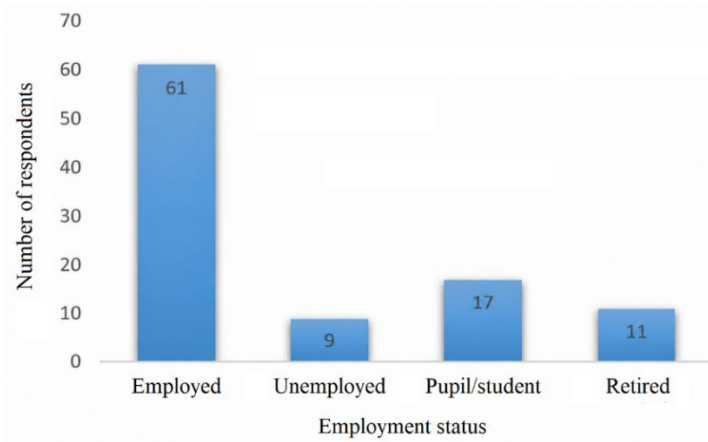


Figure 12. Distribution of respondents by employment status

This sample composition allows the findings to be considered from the perspectives of different groups of potential users.

Following data collection, the results were analyzed for each question. The findings were presented graphically to facilitate comparison. One question concerned the importance of product appearance when selecting sanitary equipment. The results indicate that aesthetic appearance is an important factor for a dominant number of respondents (Figure 13).

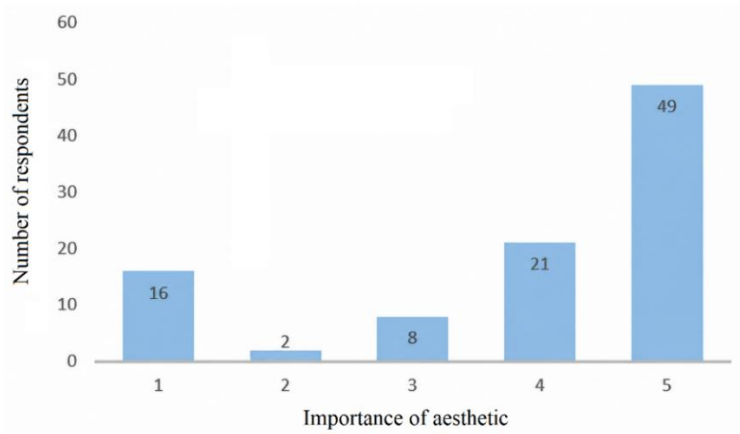


Figure 13. Importance of the washbasin's aesthetic appearance in product selection

This finding indicates that washbasin design should address both functional requirements and the product's visual identity. Form, proportions, lines, and surface finish are elements that can influence users' perceptions of a product.

One section of the survey concerned the choice of material from which the washbasin should be made. The responses to this question were used to examine users' attitudes towards traditional and contemporary materials (Figure 14).

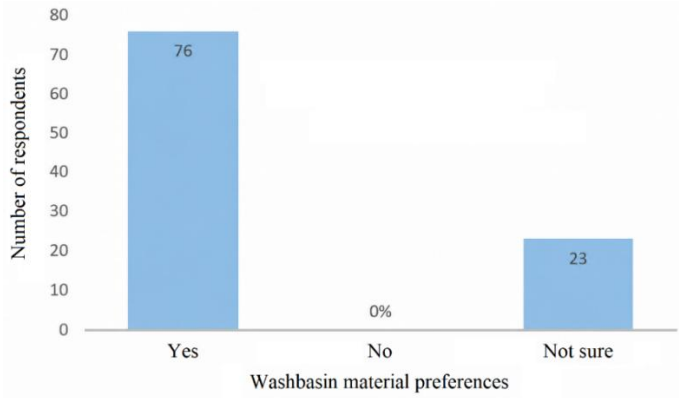


Figure 14. Respondents' preferences regarding washbasin materials

In addition to its visual appearance, the product material should be assessed in terms of moisture resistance, maintenance requirements, durability, and suitability for everyday use. Respondents were also asked to express their views on the importance of the washbasin's functional properties. The results indicate that functionality is one of the primary criteria in product selection and also that product design should be based on a balanced relationship between aesthetics and functionality (Figure 15).

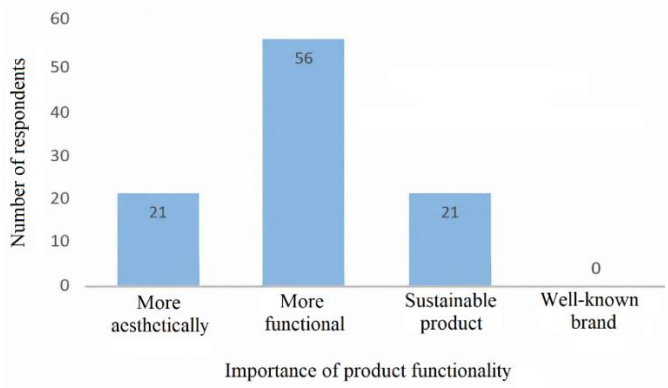


Figure 15. Importance of the selected product's functionality

The analysis of respondents' answers provided insight into the needs and expectations of potential users regarding the appearance and functionality of sanitary products. Based on the findings, particular attention was given to the product's form, proportions, material selection, maintenance requirements, and functional properties. The design process aimed to achieve a balance between visual appeal and practical usability, ensuring that the proposed design addressed both aesthetic considerations and users' functional requirements. Thus, the survey findings provided a basis for and further justification of specific design decisions.

The study provided valuable information on potential users' attitudes, preferences, and needs, enabling the identification of key factors influencing product perception and selection. The results highlighted the importance of an integrated approach to product design, in which aesthetic, functional, and material characteristics are considered collectively. Accordingly, user research served as a link between the design process and the expectations of potential users, helping to ensure that the final product design was informed not only by technical and aesthetic criteria but also by user-oriented considerations.

CONCLUSIONS

The product analysis demonstrated that functionality, design quality, appropriate material selection, and sustainability can be successfully integrated into a single product. The examination of the selected washbasin, including its views and cross-sectional representation, confirmed the functional requirements, structural precision, and consistency of its main design elements. Considering the aesthetic, functional, and material properties together provides a basis for developing a final product that responds not only to technical and design requirements but also to the actual needs of potential users. In this context, user research represents an important part of the product development and design process.

The conducted survey provided insight into the attitudes and preferences of potential users regarding sanitary products. The results indicated that functionality, quality, and durability are the most important factors influencing product selection. However, respondents also considered appearance and material choice to be relevant aspects. Furthermore, the findings revealed a positive attitude towards the use of sustainable materials, highlighting the importance of incorporating environmental considerations into contemporary product design.

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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