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HOLISTIC APPROACH TO MATERIALS SELECTION IN PROFESSIONAL APPLIANCES INDUSTRY

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1. Introduction

Materials selection is a systematic method of evaluation of the most suitable material solution for a given application. This process is a multi-criteria decision making problem, which involves seeking the best compromise between design requirements and material properties [Ashby 2011].

Electrolux Professional, one of the world leaders in the manufacturing of professional solutions for cooking, food preparation, dish washing, waste disposal and fabric treatment, recognizes the strategic importance of materials selection in its production. Professional appliances, with respect to domestic ones, are less influenced by mass production logics and the associated cost factors, while they are characterized by a more intense use in harsh environments. Moreover, professional appliances are developed as tailor-made solutions, designed to satisfy the client needs (e.g., B2B, and B2C) even in very specific operative conditions, and they are designed to be highly performing in field. The development of Electrolux Professional products requires a correct functional analysis and materials selection, especially when non-conventional processes and conditions are applied. During their lifetime, indeed, professional appliances experience specific durability problems related to food chemicals and detergent compounds' compliance, and to misuse practices. Along this direction, both a specific characterization of materials in such combined harsh environments and tools for new user-product-material interaction prediction are required. In addition, during the design phase emerged the need for investigating in which way the materials used to build a product influence how user can interact with them, in order to increase the quality perception of the product.

Materials selection for professional appliances, indeed, sees the analysis of several and different variables: technical properties, manufacturing and economic requirements, food contact compliance, durability at specific service conditions, sensorial properties, intangible meanings, user-interaction aspects, market trends, etc. Traditional materials selection methods involve systematic specifications of technical properties, but they do not integrate design requirements and the other issues in a methodical way. For this reason, in practicing materials selection, designers and engineers usually do not follow classical methods and base the research on their experience.

To overcome these limits and to organize all the previous information in a systematic and comprehensive way, the development of a flexible materials selection method able to match engineering requirements and design constraints needs for improvements. This paper proposes to adapt the traditional Ashby's method of selection, integrating it with non-traditional methods and tools for the analysis and selection of durability and qualitative properties of materials.

The holistic materials selection methodology proposed would be tested and validated through real applications in the field analysed (Figure 1). The investigation of different study cases will allow an extensive evaluation of critical points and emerging issues of the method developed.

Figure 1. Electrolux professional product division

2. Background research

In operating materials selection, product designers have to evaluate the most appropriate material solution for each product, taking into consideration both technical requirements and sensorial properties of materials [Karana et al. 2008]. For this reason, in the last fifty years, several methods and tools have been developed in order to guide materials selection activities. Engineering based methods represent the first and most commonly used methods for materials selection, and have been implemented also in industrial context. On the other hand, even if design based methods have been widely discussed in the academic field, they have not already been employed in a structured way in a real industrial case study. For this reason, in this paper engineering based methods will be named "traditional materials selection methods", and design based ones "non-traditional materials selection methods".

2.1 Traditional materials selection methods

From a literature review, most of the researches based materials selection process in materials technical properties evaluation [Deng et al. 2007]. The most valuable engineering based methods have been developed by Patton [1968], Ashby [1992], Lindbeck [1995], Bundinsky [1996] and Farag [1997].
One of the first materials selection methods was developed by Patton in 1968. Patton's method established that three basic requirements have to be satisfied in selecting product materials. Service requirements, which include an evaluation of product's dimensions, as strength, toughness, hardness, corrosion and heat resistance. Fabrication requirements that comprehend an objective analysis of the material shaping and joining characteristics. Economic requirements, which allow designer to succeed in minimizing the product and manufacturing costs.
In 1992, Ashby's team set the basics of modern materials selection, developing a systematic selection method that proved to be an efficient tool in the early stages of mechanical design. The materials selection method under consideration, indeed, is particularly useful for initial screening of materials, both on industrial and academic field, and it is always based on quantifiable properties. Ashby process, basing on the use of indexes obtained from the observation of the involved physical phenomena, provides a fair comparison between different materials classes or manufacturing processes.
Ashby materials selection, in particular, outlines the basic limiting properties of materials: general (density and price), mechanical, thermal, and wear and corrosion/oxidation properties. Years later, together with Johnson, Ashby method would be updated considering for the first time also aesthetic attributes (sensorial properties) of materials [Karana et al. 2008].
Following Ashby method, during the 1990s several researches defined the effective material aspects for materials selection process. Lindbeck [1995], for example, settled that the factors that must be

considered in materials selection should be related to the mechanical, physical, chemical, thermal, electrical, acoustical and optical properties.
Budinski [1996] ordered the requirements to be fulfilled through materials selection into four macro-categories: chemical, physical, mechanical and dimensional properties (size, shape, finish, and tolerances). Moreover, Budinski specified that market and production regulatory issues, as the ones set in the U.S. and in the European Union, represent another important selection factor. He named them "business issues". Budinski has been the first that suggested considering in materials selection also the "availability" factor. This factor, related to manufacturing requirements of availability of the material to be implemented in the production, is linked also to the business cultural background. If a desired material cannot be obtained within the constraints of this schedule, indeed, the designer should substitutes the material chosen with a material readily available for the business production.
As materials selection process represents a decision-making problem, it requires reaching a compromise between conflicting objectives. In choosing materials, the objective is to optimize a number of metrics of performance. Farag [1997] developed a weighted-properties method for materials selection, in which to each material requirement, or property, is assigned a certain weight, depending on its importance to the performance of the component analysed [Farag 2006]. The method allows depicting the most suitable material for a given application comparing the different alternatives through a "performance equation". Moreover, Farag method introduced the concepts of reliability requirements, which define the probability that a material will perform its function throughout its expected life without failure, and service conditions, which are directly connected to materials environmental properties and the design of the product.

2.2 Non-traditional materials selection methods

As mentioned in the previous paragraphs, while operating materials selection, product designers deal with both functional properties (technical properties, manufacturing requirements, and economic requirements) and some intangible aspects, in order to express their intentions in the project. More recently, the need for integration of intangible characteristics of materials in selection process gained increasing attention, especially in the academic field. Several studies focused in informing how consumers build they experience with products through materials, how materials elicit emotions and how we attribute meanings to materials [Karana et al. 2015].
Ezio Manzini [1986] is the first author that recognized materials as the basis of innovative design. He examined the way in which matter becomes capable of being integrated into a part of a product (e.g., matter becomes material) through supplying cognitive tools and cultural reference. In "The Material of Invention", Manzini embodies philosophical and aesthetic responses of Italian designers to the limits, potentials, and design implications of new materials in industrial production.
Ashby and Johnson [2002] underlined the importance of introducing aesthetic attributes of materials for an exhaustive materials selection in product design. In particular, they assigned to materials two corresponding roles: providing technical functionality and creating product personality. Redefining the requirements list in materials selection, they added eco-attributes and the aesthetic attributes of materials, which involved also the concepts of perceptions and intentions.
Karana [2008] provided critical guidelines which could help designers to include intangible and sensorial properties in materials selection process. Karana considered intangible properties those characteristics which attribute meanings or evoke emotions and cannot be identified with numerical values and cannot be perceived by senses. Conversely, while sensorial properties could be classified and quantified through direct and indirect methodologies [Zuo 2010], [Wongsriruksa et al. 2012], intangible properties express the characteristics that designers want to imprint to the product.
The dynamic action between the user and the product contribute to define the overall profile of the most suitable material for a specific application. The materials that a product is made of thus influence, indeed, how users interact with the product [van Kesteren et al. 2007]. The "Materials in Products Selection" (MiPS) tools, elaborated by van Kesteren’s research group, incorporates user-interaction aspects into the materials selection process. MiPS, which consists of three different tools (picture tool, sample tool, question tool), has the purpose to increase understanding about the desired user-interaction aspects of the materials used in a new product.

3. Holistic approach to materials selection for professional applications

The aim of this research is the development of a versatile method for materials selection in the professional appliances field, used by engineers and designers. The materials selection method under development would offer a complete evaluation of materials properties (from "technical" to "sensorial" ones), enabling the conversion of qualitative to quantitative properties and the estimation of the risk associated to the materials selection reliability. The need for a holistic approach and a unique language to evaluate the different materials properties emerged from a critical background analysis (Chapter 2), and from the examination of databases and tools currently used in the selection of materials and manufacturing processes for professional appliances.

3.1 Design setting of the method

The holistic method of selection would evaluate both quantitative and qualitative properties of materials, which could be divided in five macro-categories: technical properties, manufacturing and economic requirements, sensorial properties (related to user-product interaction aspects) and intangible properties of materials. As highlighted in Figure 2, this research will focus on the integration in the selection process of technical properties as eco-properties, durability and regulatory issues (e.g., flammability resistance, food contact compliance), and intangible and sensorial properties.

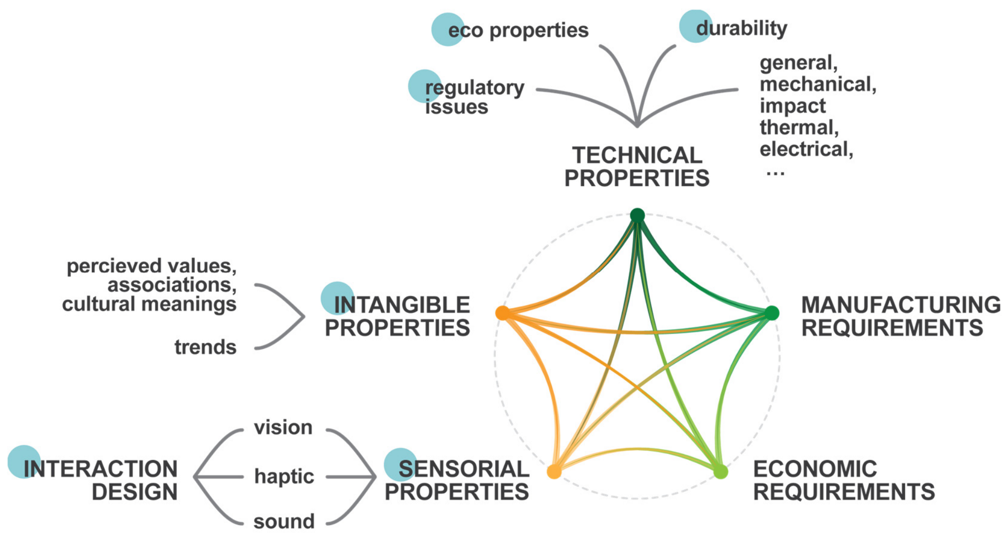

Figure 2. Effective aspects for materials selection in professional appliances

The general approach of the method, especially for technical properties, manufacturing and economic requirements evaluation, follows Ashby's process, which is organized in different steps: translation, screening and ranking, choice [Ashby 1992]. In order to systematize and prioritize the properties to be analyzed and to accelerate the first steps of the materials selection, another phase has been included in the novel process of selection: the context analysis phase, a preliminary activity to the first step of properties translation. Another innovative contribution in the selection process setting is the introduction of a procedure for evaluating the risk associated to each materials selection. The risk analysis procedure, which could occur since the very beginning of the process, uses ordered categorical labels to potentially simplify risk assessment in informing risk management decisions. Figure 3 describe the steps of the holistic method of selection under development, together with the properties that could be analysed in each process.

As explained in the previous chapters, the aim of the research is to evaluate both quantitative and qualitative properties of materials. In achieving this, the holistic materials selection process for professional appliances integrates traditional and non-traditional methods of analysis for alternative material solutions. In particular, non-traditional methods would be adapted or elaborated in order to evaluate durability and sensorial and intangible properties. In the following paragraphs, more detailed information about already developed tools and future actions in method development would be provided.

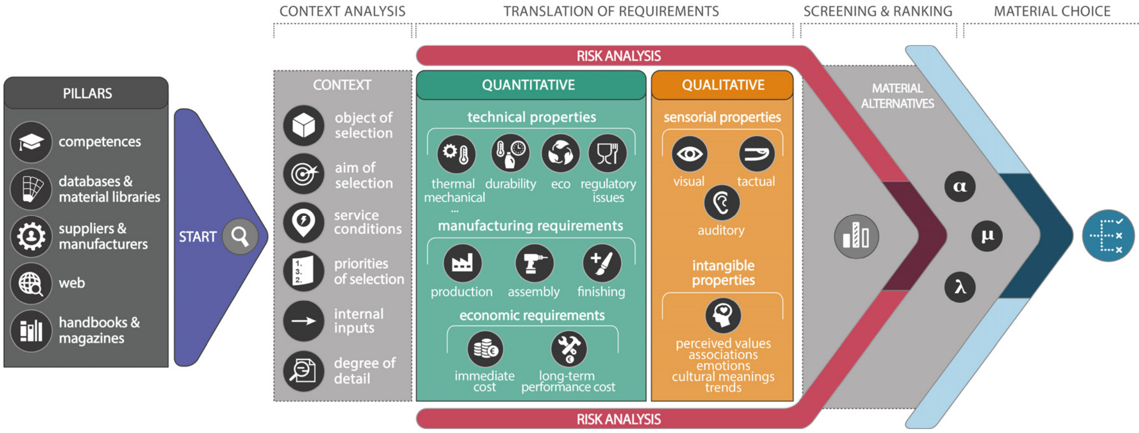

Figure 3. Holistic materials selection process steps

3.2 Context Analysis Datasheet

The "Context Analysis Datasheet" (Figure 4) represents a promising instrument to guide the materials selection, providing a structured approach for sharing technical knowledge about the product examined. The tool, described in detail in the paragraphs below, has been evaluated both in the industrial context and in the academic one during an educational experience conducted at Politecnico di Milano, within the course "Materials Selection Criteria in Design & Engineering" [Piselli et al. 2016].

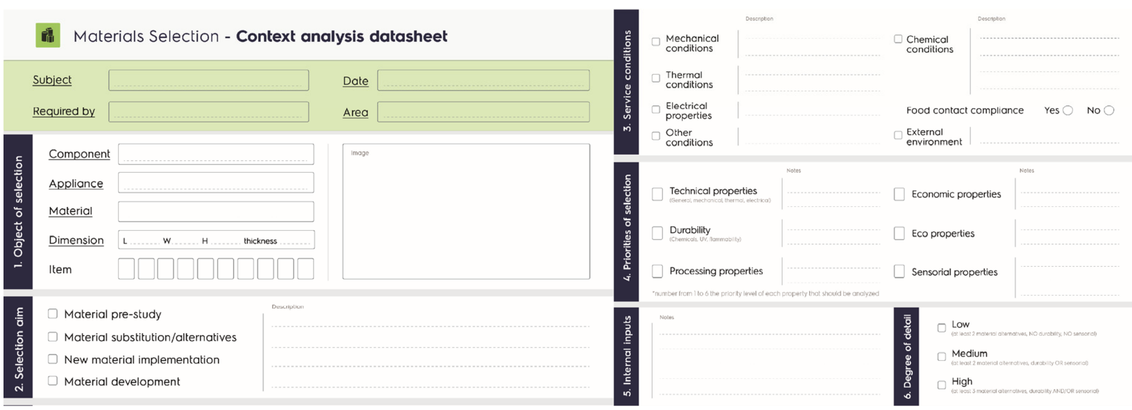

Figure 4. Holistic materials selection process steps

3.2.1 *Object of the selection*

The object of the materials selection has to be clarified and deeply described in the first phases of the process. Information about the appliance, component, dimensions, shape and material currently used will be described in this section of the context analysis.

3.2.2 *Aim of the selection*

In this preliminary phase, the aim of the selection has to be clarified. Materials selection, indeed, could enable either to find materials solutions for new applications or to search for alternative materials to be replaced in applied products. In the industrial appliances context, materials selection for substitution and equivalency is a very frequent matter, and is needed in order to respond to material failures, changes in manufacturing processes, increase of performances, regulatory problems, materials obsolescence, materials supply disruptions, to meet strategic objectives on cost or eco impact, etc.

3.2.3 Service conditions

The environment in which the professional appliances or their components work plays an important role in determining the material performance requirements [Farag 2006]. High temperatures (e.g., hot category appliances), as well as cold temperatures (e.g., blast chillers and refrigerators), harsh environments (e.g., washing environments exposed to acids and bases), or corrosive environments (e.g., special business solutions for marine environments), can adversely affect the performance of most materials in service.

3.2.4 Priorities of the selection

Related to the definition of the selection's aim, it is valuable to assign the priority of the properties that have to be analysed during the process. For example, if the aim of the selection is material substitution for cost reduction, high priority will be given to economic requirements analysis. On the other hand, in durability oriented selections will be assigned high priority to the analysis of technical properties (e.g., chemical properties) rather than to perceptual ones.

3.2.5 Internal inputs

Some suggestions based on the experience and knowledge about the product/component analysed, could be added in this phase of the materials selection by the professionals of the company.

3.2.6 Degree of materials selection detail

Depending on the aim of the selection, on the complexity of the context in which the component/product operates and on the variables to investigate, different degrees of analysis' detail can be distinguished in: low, medium and high detailed material selection.

3.3 Quantitative properties

Inspired to the basic procedure of Ashby's selection, the constraints of the investigation have to be translated into properties limits, which would be evaluated in the "Screening & Ranking" phase. In the translation of quantitative properties of materials, with the exception of durability properties, also in the novel method of selection takes into account the categorizations that Ashby adopted in building the Cambridge Engineering Selector (CES).

3.3.1 Technical properties

Some of the technical properties that could be commonly analysed during a materials selection for a professional appliance are illustrated in the figure below (Figure 5).

Category	Example properties
General	Density
Mechanical properties	Young's modulus, Compressive modulus, Flexural modulus, Shear modulus, Bulk modulus, Yield strength, Tensile strength
Impact properties	Impact strength, notched and un-notched
Thermal properties	Melting point, Glass temperature, Heat deflection temperature, Thermal conductivity
Electrical properties	Resistivity, Dielectric constant, Dissipation factor
Durability	Flammability, UV resistance, Chemical resistance

Figure 5. Examples of materials records data that CES Selector contains in each category

One of the most interesting aspects to be developed in the materials selection method tailor-made for professional appliances is related to durability properties of materials. The nominal information supplied by CES Selector about durability properties, indeed, is useful in case of a quick preventive selection, while it gives lacking information of the interaction between the material and a particular chemical compound. This limit is particularly evident in professional food processing appliances, in which

interact many detergents, composed of an acid or alkaline base with the addition of surfactants, and food chemicals, as oils and fats, sodium chlorides, carbon residuals after food cooking, etc.
The interaction among these chemicals and materials can induce different failure mechanisms in the considered material, more than a shortening or an extension of components' service life. The key point for the evaluation of durability parameters in materials selection is the association of a numerical parameter with a nominal indication for each class of materials. These parameters have to take into consideration also the properties' change in time, even for both linear and nonlinear trends.
Supported by an active collaboration with experts of the company, non-traditional methods will be applied in chemical experiments in order to simulate the use of the appliance and testing the materials reliability on time.
In the novel method of selection the Budinski's [1996] "Business issues" are named "Regulatory issues", and assess the compliance to country regulations. In professional food processing appliances high importance would be given to food contact legislation compliance (e.g., FDA 21 CFR, GMP 2026/2006/EC, Framework Regulation 1935/2004/EC, etc.).

3.3.2 Processing properties

The analysis of the processing properties represents an additional factor in selecting materials for a specific component. Both material and process selection must be considered simultaneously, as not all materials are compatible with every manufacturing process. Each processing property, characterized by a set of attributes, has been conveniently displayed in matrixes and charts by Ashby [Ashby 2011]. Together with processing properties displayed in the CES Selector (e.g., Melt temperature, Mold temperature, Shear-Thickening Fluid, etc.), these tools will be used in the novel method of selection in order to confront which conversion process would be the more suitable for casting, forming, joining, and machining a certain material for a specific component.
The process matrixes used in the novel method of selection will be: the process-material and process-shape matrixes, and the process-mass-range and process-section thickness charts.

3.3.3 Economic properties

The analysis of the cost of the material, as well as manufacturing costs, is fundamental information for each materials selection. The "Part Cost Estimator" function available in CES Selector, allows considering the cost of the component since the early stages of conceptual design.

3.4 Qualitative properties

Including sensorial and intangible properties in materials selection process is a complex issue. As evidenced in the background analysis conducted in Chapter 2, non-traditional methods of selection could be valuable instruments to allow the translation of qualitative properties in the process of selection.

3.4.1 Sensorial properties

The expressive-sensorial characterization of materials allows to describe, design and select materials, determining the phenomenological aspect of them on the basis of their physical and technological properties. One of the specific objectives of this research is the implementation of tools for quantification and classification of sensory preferences of users in an objective way. Analysing different studies and methodologies [Barnes et al. 2004], [Zuo 2010], [Wastiels et al. 2012], [Wongsriruksa et al. 2012], [Faucheu et al. 2015], Sensory Metrology and Sensory Evaluation Analysis have been detected as instruments for sensorial properties evaluation in the process under development.
Within non-traditional Sensory Metrology methods, the "Napping® Test" [Faucheu et al. 2015] has been selected to translate sensorial properties of materials in a numerical system (e.g., range of values), in order to obtain a more concrete and comparable result, and to depict the "Material Sensory Profile". The "Napping® Test" will be adapted to the context of professional appliances through an accurate selection of descriptors related to the visual, tactile and auditory sensorial properties. The panel group, which will compare different materials physical samples through their sensorial properties, consists of both professionals selected from different sectors of the company (e.g., R&D, Quality, and chefs), and design students.

3.4.2 Intangible properties

Intangible characteristics of materials represent the characteristics which are attributed meanings or evoked emotions and they cannot be identified with the numerical values and cannot be perceived by senses (e.g., emotions, meanings, effects of cultural background, trends, etc.). In order to detect expressive/semantic characteristics of materials, physical materials samples could be used in aesthetically oriented materials selections. Using a sample tool in the defining phase of materials selection, would help designers to compare different materials profiles [van Kesteren et al. 2007].
The trend analysis of materials could guide materials selection. Even if professional appliances aesthetic, compared to the domestic one, is less influenced by current market trends, the trend analysis could evidence if some materials applied to a specific product have been substituted by more performant materials and more appreciated by the user. Moreover, the connection among technical and sensorial properties could be the key point to get a unique direction of materials selection both market/consumer-oriented and technical/performance-oriented. Trend analysis tools would be developed within the novel method.

3.4.3 User-interaction aspects

Linked to the usability of the product, the material user-interaction aspects are those that influence the personality of a product. For example, in the automotive field, the quality of a car is rated on the basis of the sound produced by closing its door [Kuwano et al. 2002], [Törnqvist et al. 2011]. Although, during the materials selection process designers are not always able to clearly identify the user-interaction aspects of materials they desire in a product. The analysis of user-interaction aspects could help in early stages of materials selection to detect the sensorial properties required in a specific product.
Among different user experience methodologies [Fenko et al. 2010], [Vergara et al. 2011], [Bordegoni et al. 2013], [Ferrise et al. 2013], "Perceived Quality Tests" have been detected as appropriate procedures of investigation both to examine physical properties of materials, both to evaluate the relation of some descriptors (e.g. adjectives) associated to the perception of a specific product/component by the user. "Perceived quality tests" from the automotive field would be adapted to the professional appliances one and proposed to an internal panel in order to quantify qualitative visual, haptic and sound perception of products [Piselli et al. 2015].

4. Discussion

The materials selection methods currently employed in industrial field are engineering-based, and generally involve specifications of technical properties, but they do not integrate methods for the evaluation of design requirements and other issues (e.g., durability, risk assessment) in a systematic way. Design research can add innovative contributions in materials selection method development. Analysing the different approaches adopted by engineers and designers in materials selection, design research recognizes the need for an integration of the processes, enhancing the strong points of both approaches. Moreover, through design research, traditional and non-traditional methods of investigation are defined in order to draw the shape of the holistic method of materials selection. The case study based research, applied to the professional appliances field, allows an extensive evaluation of critical points and emerging issues of the developed method of selection.
In order to help product designers during the materials selection process, some specific tools have been developed (e.g., context analysis datasheet, risk assessment procedure, sensorial properties atlas and maps), and others are under development (durability properties evaluation method, Napping® Test, Perceived Quality Tests, etc.).

5. Conclusion

The study set the basis for the development of a new method of materials selection, used both by designers and engineers, specifically designed to be applied in the professional appliances industry field. The approach adopted in structuring the new selection method is holistic: its purpose is to compare qualitative and quantitative properties of materials: technical and durability properties, manufacturing requirements, economic requirements, sensorial properties, intangible properties and user-interaction aspects. The method, tested on specific case studies, would provide further insights into the development of new products. This will therefore bring opportunities to the company to show its competence on the market with products ready to demonstrate attention to product's performance, environmental requirements, market trends, user needs and user-product-interaction aspects.

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