An Overview of Product Design Evaluation Methods and Techniques

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Abstract:

The study covers a brief outline on extensive product evaluation methods and techniques from discipline literature and best worldwide practices to overcome design problems and to develop the resources needed to maintain production development. Validated design evaluation methods are identified that help product development optimize its designs to monitor compliant design processes and provide timely, cost-effective solutions and meet safety, customer, and legal requirements. The study is structured to view the state-of-the-art on product design processes evaluation, product design evaluation issues, methods and techniques. The results of this study can be used as a useful tool to help designers, industry professionals and academics working in either product design or product evaluation sectors such as design students and design assessors, project and product managers, and researchers, teaching academics to further improve the completeness, consistency, and creation of an accurate and modifiable product design. The conclusions summarize the main results and open future work avenues.

Keywords:

Product Design Evaluation, Human-Centered Design, User Experience, Qualitative Evaluation, Quantitative Evaluation Evaluation Methods,

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1. Introduction

This study has been structured to review the latest views on product design evaluation methods and techniques. The study covers a brief introduction on extensive product evaluation methods and techniques from discipline literature and best worldwide practices to overcome design problems and to develop the resources needed to maintain production development. Validated design evaluation methods are identified that help product development optimize its designs to monitor compliant design processes and provide timely, cost-effective solutions and meet safety, customer, and legal requirements. The results of this study can act as a practical tool to assist designers, industry professionals and academics working in either product development and/or product evaluation sectors such as design students and design assessors, project and product managers, and researchers, teaching academics in improving and further developing the completeness, consistency, and creation of an accurate and modifiable product design evaluation. The conclusions summarize the main results and open future work avenues. (Cross, 2021)

Product development and product design processes are regarded as important stages that determine the quality and cost of a product's design and its sustainability in terms of production and use. Product development undergoes various evaluation stages to explore previously identified design problems and opportunities. The specific stage transitions regular production goals and schedules and needs the product development to stop or slow down to recover. (Roberts et al., 2020)

Computer-aided design systems with linking structural and other design tools can be used to predict the behavior of a product with reasonable accuracy. Reliability grows with the increased use over a wide range of designs fully described digitally. Special computer programs are available for rough-and-ready predictions of user responses: students taking examinations and completed designs tested via simple user trials. They all are best thought of as investigative tools, useful for quick comparisons between several design alternatives before more detailed information is required for rigorous evaluations. We have learned that the appeal of a new product is very construct-specific and related to its ability to meet the perceived need, to be easy to use, to fit well into the user's (often busy) life, to be reassuringly well-made, and to give satisfaction with the feeling of ownership. However, they do not add up and have different importance in different products and for different people. (Meyer and Norman2020)

An important aspect of integrated design in new product development is technical and engineering information in order to ensure a good evaluation of design solutions and the subsequent decision-making. In product development, the latter should occur at two levels. Firstly, the suitability of the new product in relation to customer needs must be assessed in such a way that designers can specify the desirable attributes of the product before design solutions are searched for and evaluated. Most evaluation comes under one of three headings: Engineering Evaluation – based on how well the design meets objectives; Economic Evaluation – based on cost or commercial reasons; Human Factors Evaluation – based on human characteristics and responses. Limiting the number of engineering properties is cost-effective in terms of test programs.. (Cross, 2021)

Research problem:

Design evaluation is tool to minimize the gap between design concepts and the actual realization of these concepts and improve the efficiency of the design process by reducing uncertainty. Evaluating existing products sharpens market strategies. It plays a critical role in determining the time to market and increases the likelihood of success in product development. Design evaluation can be carried out at any stage of the design

process, from concept generation through production. Therefore, it plays a major role in providing a convenient and most efficient product to the targeted consumers. The problem of the current study can be summarized in; What and to what extent can product deign evaluation methods be employed to enable designers achieve their goals in design.

Research objectives:

The aim has been to develop a multifaceted investigation and a deep understanding of current and future product design evaluation methods.

Research Methodology:

To achieve the above goal, the research followed a deductive approach to identify some major factors contributing to structure of evaluation methods concepts of research such as through the literature that dealt with these topics and the role of architects in achieving the principles of sustainability through , then the inductive approach to study and analyze some international and Egyptian case studies.

2. Theoretical Framework

2.1. Product Design Evaluation

The term "product design evaluation" in this study refers to an activity conducted by designers in product development efforts that involves the assessment of a design or a design prototype. The term "prototype" refers to both physical and digital models. In this study, we consider physical prototypes as valid for product design evaluations.

2.2. The Importance of Product Design Evaluation

Product design cases can be examined in dozens of different product categories. More common design evaluation techniques typically focus on one or more likely characteristics of a product (such as its performance, manufacturing cost, and its market). As the description of work on product design cases illustrates, product design evaluations can be quite specific. Companies often use design evaluations and product design attributes as leading indicators. This is true at all stages in the product life cycle. Whether for a new product opportunity, the concept generation stage in new product development, the detailed design stages, or later in the product life, all areas of the business, manufacturing, and life-cycle management of the product play a role in the decision-making by companies throughout the product life cycle. (Yulianti & Sulistyawati, 2021)

Whether product designers come from industrial design, mechanical engineering, or some other design discipline, they have a significant influence on the product that is designed. The influence is not accidental, but rather, it has been earned through education, training, and project experience. There are two general approaches for examining what designers bring to the design process. In some research work, it is common for the academic community to examine a large number of product design cases to develop a list of what distinguishes the successful designs from the technically successful designs, but for some reason did not succeed in the commercial marketplace. (Elkhattat & Medhat, 2022)

The characteristics of product design are partially the cause of this confusion. Firstly, the designer typically values not only technical characteristics, in other words function and performance, but also marketability and affordability. As such, the designer sets multiple goals, and in principle, each design solution has its own standard because it is rare for a single product to compete using only this characteristic. Therefore, the design has been allocated not only the performance standard but also various other standards, which has made the situation complex. Secondly, design is now generally understood as an activity in which advanced creativity and intelligence are exercised to solve ill-defined problems. The designer deals with many ill-defined problems by groping between the goals, sub-goals, and constraints, and by solving them recursively. Formally assigning the target to evaluate, even if possible, it should merely express parameters that allow an actual solution. Overall, the problem-solving process of design is, in principle, only inductive reasoning based on case studies, analogy, and heuristics.

Evaluation is an essential activity in the practice of product design as the purpose of evaluation is usually to determine how well a solution solves a problem, to gain information that might lead to a better solution, to provide a learning opportunity relating to an analysis or solution, and/or to establish a standard or degree of capability. The importance of the evaluation of design is therefore, confirmed by a number of empirical results. However, the theoretical foundations of this activity are not clear. Even in engineering, research has not been extensively conducted. The confusion causes situations in which we are unable to grasp the significance and relationship of evaluations. (Srinivas Athreya, Y.D.Venkatesh, 2012)

2.3. Human-Centered Design

The essence of human-centered design is to ensure, in the initial stages, the cooperation of users and their real needs. This methodology attempts to understand human behavior and requirements; to envision new product concepts that are well adapted to the future conditions of use; for example, emotional appeal, ease of use, safety, ergonomics, and availability; and devote design efforts to developing products aimed at achieving the objective of an easier-to-use product with low costs. This philosophy, designed and applied in a systematic and productive way, promotes the development of products conceived for the future in order to be increasingly accessible to a wide range of people. (Carol Righi and Janice James, 2007)

Nowadays, the market is increasingly saturated and demanding, driven by increasing competition, globalization, and the ubiquitous use of new information technologies. The increasingly technological advance, which makes possible the almost instant production of an existing or new product, contributes to the early saturation of the market and to the weakening of new launch products. Product development must be done rigorously and planned with the control of all possible critical variables, minimizing wherever possible the risk of failure. The evolution of goods production has been the opportunity to increase increasingly towards the resolution of problems related to quality and in the sense of the rapid development of goods. (Coronato and

Cuzzocrea 2020)

2.4. User Experience in Product Evaluation

The important aspect of a successful evaluation is the need to include user-related aspects of the product and informal evaluation methods. Studies have shown that the usability initiative is used to evaluate products at different stages of the design cycle from early requirements to testing out product concepts and prototypes, but usability initiatives often stress professional interaction and only feed limited amounts of user feedback into the design process.

A new product receives very short time from evolution to purchase or rejection by users, which means companies are asked to reduce the time and cost of the product development and research process while enhancing the safety and efficiency of the products. A key to accomplishing both this increase in quality and its corresponding decrease in time and cost is through the integration of user experience into evaluations of product design. Indeed, all stakeholders in the user experience paradigm recognize the importance of product evaluations that include user experience. For example, ISO 9241-11 standard defines user experience as "an outcome of design aspects on a human-system interaction and context used in work, and an effective connotation on how the user expression aspired or realized. The goals of most design activities are to fulfill particular needs and to meet market demands, to appeal to human preferences, to provide functionality, and to satisfy other human requirements.

Among the many benefits of utilizing user experience in product design are:

- Enhancing Usability
- Improving Customer Satisfaction
- Increasing Product Adoption

2.4. Product design evaluation methods

A design task, subsumed in the creative act of design, is also associated with design rationale, using computer-based systems in design, in a production method, and also in a decision-making framework. Among others, a compilation of ideas, concepts and heuristics that constitute a knowledge base for embarking on the design task is important. One important component of such a knowledge base is design directions or guidelines. Designing excellence is a constant quest for all organizations, including product manufacturing companies. Achieving such business goals requires a designer to address certain issues adequately at all stages of product realization. As a generalization, all design activities performed by a designer can be grouped into major categories, viz. configuration design, size design, shape design, and technology design. Each of these design activities is important for realizing a comprehensive engineering design. (Saleh, 2020)

Following Pahl and Beitz (1996), they distinguished between the coding of norms (such as one that specifies a product's technical specifications) and a set of directives that guide human actions, a design task of taking general concepts stated in the study of (P. Dwivedi and Karl T. Ulrich, 1996).

Until recently, evaluating product design largely relied on the subjective judgment of experts and designers, particularly in the early stage of the development process. The use of engineering techniques is mainly based on the functionality of the product that is already determined. Subjective opinion introduces uncertainties, considering that designers see the design in their own way and experts' views about a specific design can vary greatly. Secondly, subjectivism is open to individual preferences and biases. Evaluation activities in the form of ideas, sketches, concepts, and prototypes often need integrated and quantitative assessment. Therefore, there is a significant demand for tools and techniques that support the evaluation of the design before making the decisions of the final design. Thus, in order to complement the support of those that conduct the design project, the tools and techniques need to be proper in terms of system approximation and formalism. But, there are methods that are incorporated into company design culture and, as such, there is neither an easy way on how to measure their performance. Our current study is based on this principle and it focuses on methods commonly used by industry. (Hesser) (Horváth, 2022).

The most Common Product Design Evaluation Methods may include;

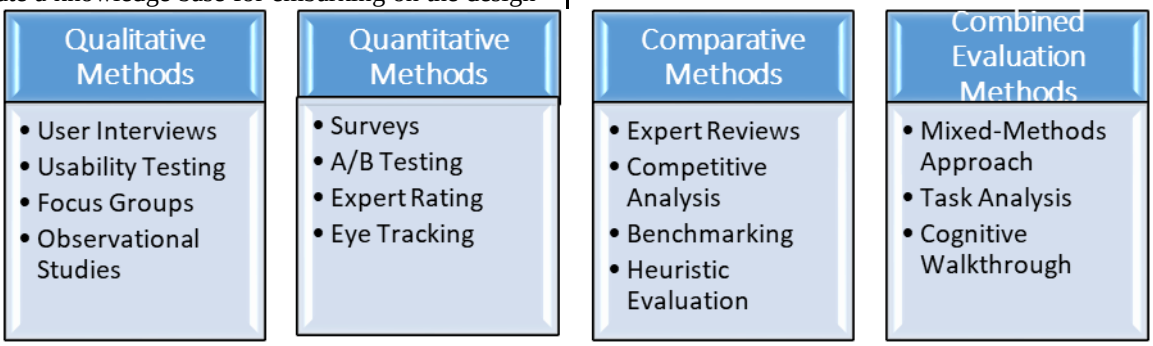

Figure (1) Common Product Design Evaluation Methods

Covering all this set of methods may require much more than this paper, therefore it is going to concentrate on the major and most commonly used ones.

3. Qualitative Evaluation Methods

Existing qualitative methods do not have the details of quantitative methods but can be more flexible than quantitative methods, particularly when they are used to study a small range of complex behaviours. They are widely used, especially in the area of graphic design, and widely employed by design academics for work in the aesthetic field. Although even these methods are expensive to run, qualitative evaluation techniques can

be less costly to put into practice than other research methods and yet can bring considerable insights to our understanding of the user. (Busetto et al., 2020)

The importance of qualitative evaluation methods is apparent when we see that many of the existing methods that are followed are mostly in the domain of qualitative rather than quantitative. Unlike, qualitative methods such as Aesthetic Assessment and Similarity and Preference Judgment are mostly employed in the early stages of the design evaluation process and analysed by aesthetics experts. DESIGN CAMP, GALILEO, and DAPS are widely used as suitable tools and focus more on the customer perspective in their assessments. Techniques such as Repertory Grid and Prototype are also widely used for work at the earliest stages of a project as well as in the evaluation of the post-design process. (Leavy, 2022)

- User Interviews
- Focus Groups
- Usability Testing and Prototypes
- Observational Studies
- In-Person Observation
- Market Research

3.1. User Interviews

The user interviews can deliver various forms of information and may be conducted at any stage of the design process to understand users, uncover their needs and requirements, assess their satisfaction, or assess the usability of the product. Qualitative data is defined as non-numeric and unstructured or free-response data. In this case, people are asked open questions, and their responses are in the form of descriptions. The interviews can be classified as structured, semi-structured, and unstructured. Structured interviews use predefined questions asked in a set order. Participants give a yes or no or a set of fixed responses. Semi-structured interviews use predefined questions and responses but can also contain open-ended questions where the participants can expand on the points, clarify the answers, and offer feedback. Unstructured interviews contain open-thought questions without predefined responses, allowing the participants to express their thoughts in a narrative form. (Rai et al.2022)

The user interviews are a qualitative research technique. It seeks to gather information about a particular topic from the users' perspective. Interviews produce in-depth information about a particular topic because they provide more space for participants to express themselves in a self-organized, contextual, and non-fragmented way. Thus, interviews can be used not only to reveal what respondents are thinking and feeling but also why and how they have these thoughts or feelings. Moreover, interviews can also be used to collect respondents' ideas, opinions, motivations, attitudes, and concerns about the research issue. (Gordon & Langmaid, 2022)

3.2. Focus Groups

Focus groups offer a dynamic alternative to one-on-one interviews. Bringing together a small group of participants fosters group dynamics, allowing researchers to observe interactions and gather collective insights. This method is particularly effective for exploring diverse perspectives, uncovering shared experiences, and understanding group dynamics that might not surface in individual interviews. Remember that your designs will be used by multiple users different from one another.

There are several benefits or advantages to using focus groups. For example, it might lead to ideas special to a small group of people that would not be obtained from a larger group. It can also give the facilitator the chance to uncover hidden or missed opportunities that the team may not have known about. However, it is also time-consuming and can sometimes be influenced by the louder people in the groups. It requires an insightfully skilled and experienced moderator and can be expensive to conduct with a small group of people. (Gordon & Langmaid, 2022)

A focus group is a form of qualitative research in which a moderator engages two to seven people to come together for approximately 1 to 3 hours to discuss their thoughts and feedback about a concept, idea, product, or service. A focus group is typically conducted before a product is released into the market. When used in product development, a focus group helps a company determine how the public reacts to a product concept or idea. The feedback from a focus group is often used to refine and improve products. Techniques used during the meeting can include questionnaires, surveys, or simple discussions. (Adeoye-Olatunde and Olenik2021)

3.3. Usability Testing and Prototypes

Usability testing involves evaluating the effectiveness of a product's interface through real-time user interaction. This alternative method employs prototypes or actual product versions, allowing researchers to observe users navigating the system. Usability testing provides insights into user interactions, pain points, and preferences in a controlled environment. By incorporating prototypes, designers can assess the functionality of specific features, ensuring a user-friendly design. This method is especially valuable for refining the user experience iteratively, based on direct user feedback, ultimately leading to more robust and user-centric design solutions.

3.4. In-Person Observation

In-person observation involves directly witnessing users' behaviors and actions in their natural environment. By immersing researchers in the users' context, this method unveils nuances that may be missed in a controlled setting. The in-person approach provides a holistic understanding of how users integrate products or services into their daily lives. Designers should conduct the observation without external influence on the subject user’s behavior.

3.5. Market Research

Market research extends the scope beyond individual user experiences to broader market trends and preferences. This alternative leverages quantitative data, surveys, and statistical analysis to uncover patterns at a larger scale. Market research complements user interviews by providing a macro-level understanding that informs strategic decisions and market positioning.

Discovery research focuses on the initial exploration of a problem space or a new product idea. It involves gathering insights from various sources, including user interviews, surveys, and secondary research. By combining diverse methods, discovery research lays the foundation for understanding the landscape before diving

into more targeted investigations. Rather than relying solely on one method, integrate various user research methods to understand user needs comprehensively. You can get insights from different angles by combining interviews, usability testing, and surveys. This eventually results in more informed and user-centric design decisions.

4. Quantitative Evaluation Methods

The product design process widely used in product development life cycles comprises a series of parallel and sequential design activities. The focus is then directed into the sales and market position and emphasized on shortening the product development life cycle. For improved evaluation of the needs in product design, the proposed product design evaluation model and its methods and techniques have to be introduced at the early stages of product development processes. (Hapuwatte & Jawahir, 2021)

The design, development, and introduction of a new product offering are important means through which an organization can gain an enduring competitive advantage. In this context, our purpose is to achieve better design by using various product design evaluation methods and techniques. The numerous computer-based techniques and methods developed for product design evaluation can be classified into both quantitative and qualitative methods. The choice of either a quantitative or qualitative method for behavioural design evaluation is based on the specifics of the product design itself. (DebRoy et al.2021)

The next stage is to compare the product's and consumer's viewpoints, and it can also provide some control over marketing the product. Such control would enable optimal market positioning with regard to the target group in terms of price and design. To do this, evaluations of certain models are used, which can be divided into two main groups: those characteristics that can be quantified and those that cannot. (Pessoa & Becker, 2020) Although groups of evaluators, such as potential buyers, can determine a product's overall quality with a single word or a brief expression, this is not enough. The evaluator should verbalize the characteristics and judgments to provide an understanding of the process. (Pandi et al.2020). Quantitative Methods include;

- Surveys
- A/B Testing
- Expert Rating
- Eye Tracking

4.1. Surveys

Surveys are used with high frequency in organizations and government for a wide number of purposes. Surveys are often employed in engineering organizations to gather information and feedback about engineering design concepts that organizations might undertake. Generally, these surveys are done via mail or meetings. The possible user segments that can be surveyed are internal organizational personnel and external organizational personnel. This external segment may include technical professionals, clients who contract with the firm for services, and potential users of the proposed design. Such meetings might occur, in a sales firm, at a trade show or field sales office. (Stantcheva, 2023)

There are also at least two articles that provide guidelines for selecting a method to evaluate product design concepts. The number of methods and techniques selected for a product evaluation study must be small enough that it is manageable within the large list of tasks design engineers have been given. Certainly, some types of data must be gathered directly from users to be valid for the subsequent decision-making, but these users of the design will be few, such as maintenance personnel, or graduate students of a professor who are willing to be a proposed user to gain insight. So, design engineers must rely as often as possible on sources beyond the direct applications of the product to gain design evaluation data. (Hiebl, 2023)

4.2. A/B Testing

In A/B testing, users are divided into two groups: users that receive the current version of the system (or the control group) and users that receive the new version of the system (or the experiment group). Users in the control group receive recommendation lists calculated using the current parameters. On the other hand, users in the experiment group receive recommendation lists that are calculated using the new set of parameters. In the context of large-scale recommendation systems, A/B testing is the best way to ensure that online experiments provide high accuracy results about which methods/systems work best. However, to show that the new recommendation system is better, a sufficiently high number of users must be included in the experiment; this requirement can be very hard to fulfill.

4.3. Usability Testing

Usability testing is a method used to evaluate how easy it is to interact with the user interface of a product. It is the most effective method to understand the easiness of operating software, with harm minimized. Usability testing is a thoughtful, planned, structured, and conducted study in a controlled setting about how valuable and effective a user interface's characteristics are. As part of the process of formative testing, the product designer may employ usability testing. Usability testing can validate how effective chosen design possibilities are to make memorable the most common and recurrent operations users must conduct in order to satisfy their objectives, in a way that is efficient, easy, and stress-minimizing. In this way, the user-interface design team helps defend recommended modifications. (Aiyegbusi, 2020)

Usability testing measures the usability, efficiency, and effectiveness of an item, as well as the ability of the item to provide satisfaction to its intended users. Usability testing often permits the identification and indication of problems in item design and overall performance before production. Usability testing also permits a very specific analysis of comparative item designs or a comparison of existing or current item designs. The basic usability process consists of test planning, data collection, data analysis, and results and action realization. Usability test design requirements stem from research evaluation criteria and purposes, and considerations for user uniqueness and individuality in the conduct of the test. Usability testing provides a direct and unambiguous feedback process to those who are responsible for item design and development and who are the evaluators and users. (Barnum, 2020)

4.4. Eye tracking

Eye tracking is a crucial technology to help us

understand human behavior and the underlying thinking processes. Its applications are limitless, both in research and commercial use.

Overall, eye and gaze tracking technology provide invaluable insight and opportunities. To unpack its complexity, let's explore the fundamental questions of what is eye tracking, how it works, and what are its applications. Eye tracking enables the measurement of eye movements, eye positions, and points of gaze through various technological processes. In other words, eye tracking identifies and monitors a person's visual attention in terms of location, objects, and duration. EYEWARE, (2024)

When considering product design evaluation, a significant motivation for tracking changes in perceptual data-collection behavior (e.g. gaze) is that the characteristics and behaviors of elements can inform the level of attention given to them. This inference holds especially for computer interfaces, anatomically influenced by visual designs. Ergonomically, elements that are of physical or cognitive importance are almost intentionally displayed on a display's interface in high-attention or focal areas, and their visual prominence often increases as their functional or semantic importance increases. Elements of lesser importance are often visually de-emphasized relative to their more intricate "foreground" counterparts and can sometimes be perceptually ignored. The resultant user interaction can be a linear, monotonic relationship between screen position and its visual importance.

Evaluating the efficacy of a product design can be simultaneously a very tedious and difficult task. The definition of "efficacy" depends on the product's intended usage, and examples are perceived quality, usability, and anticipated delight. Factors of efficacy can also be stratified by sub-group attributes such as individual skills or preferences. (Siyu Zhu,Jin et al, 2022)

5. Comparative Evaluation Techniques

- Expert Reviews
- Competitive Analysis
- Benchmarking
- Heuristic Evaluation

The leading-edge product design companies use formal agent-directed design automation systems that use AI, which have built-in knowledge of and automatically use most of the feasible product design evaluation techniques, alert product designers to use other work that has been done in the company and suggest when it is time to do some other work before computer analysis, prototyping testing, and the like. (Dell'Era et al.2020)

Numerous methods and techniques are available to the designer for analyzing and evaluating the many complex aspects of a product in a discipline, such as human factors, system performance, and manufacturing implications. This chapter has presented over 50 different evaluation techniques that provide a forum for the many factors that need to be reviewed in product design. (Granato et al.2020)

5.1. Expert review

A design review is the result of a set of research methods that involves an analysis of a design. This is usually carried out by UX expert using their knowledge and experience of testing products with users in the shoes of a typical user. The aim is to recognize usability issues and strengths. The expert will spot problems and recommend changes to improve usability when budgets and timescales don't allow for user research.

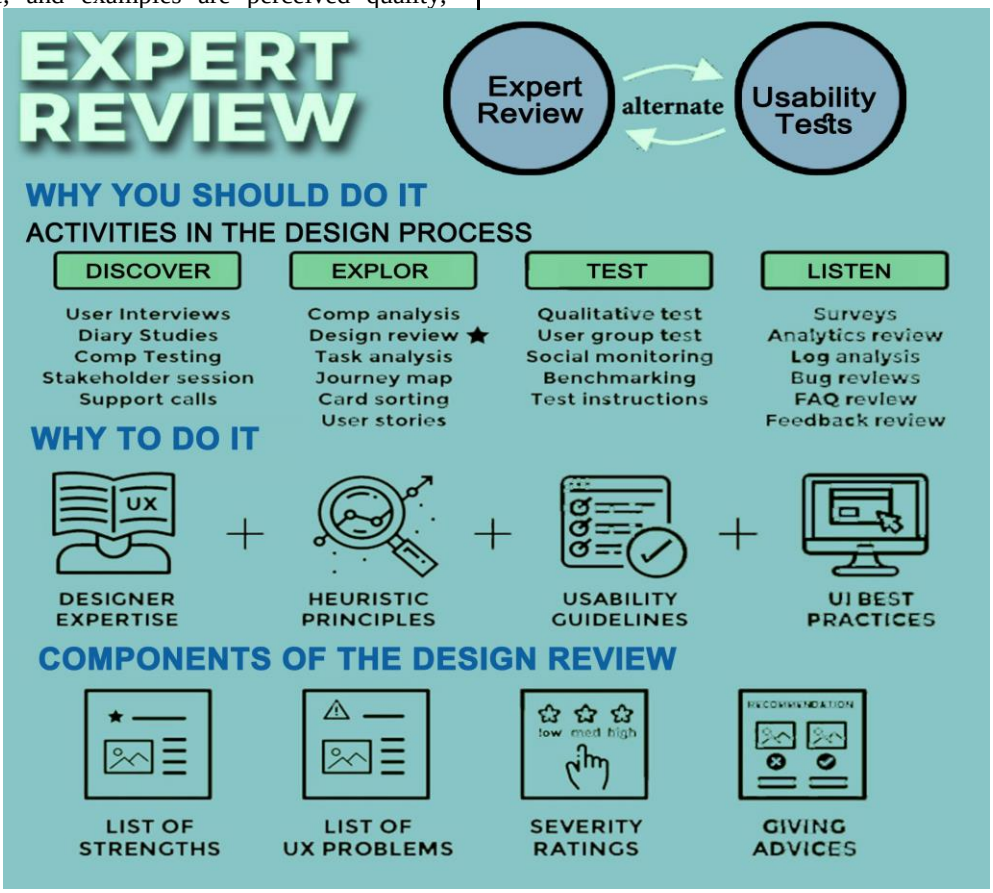

Figure (2) A diagram showing expert review features

The core components of a design review are:

- List of usability strengths
- List of usability problems,
- Severity ratings for each usability problem
- Recommendations for fixing each usability problem
- Examples of best practices to guide improvements

4.2. Competitive Analysis

In this work, we explore two alternatives to traditional evaluation: interleaving and continuous active learning. Both methods are more closely tied to user satisfaction. More specifically, interleaving relies on actual user choices to evaluate ranking proposals, while the underlying assumption of continuous active learning (or CAL) is that new training examples generated from users improve the coverage of the true underlying utility function, i.e., coverage of the user happiness with a set of ranking propositions. Our goal here is to compare these two evaluation methodologies and understand under what circumstances we might want to use one instead of the other. While our focus is on evaluating ranking algorithms, our methods do not depend on the specific technique used to generate the ranking proposals. Our comparative analysis also helps improve previous theoretical results on interleaving and active learning for evaluating ranking algorithms in web search. In the last decade, with the rise of personalized search, web search improved significantly but also became harder to evaluate. In traditional evaluation, training and test data are collected independently, with the test data being created after training is done. However, personalized search relies on the fact that the test data will be similar to the training data and on repeated close exposure to individual users to learn. It is hard to ensure that traditional evaluation measures adequately capture user satisfaction.

4.3. Benchmarking

In product development, limited resources, new products, uncertain markets, the need for integrating technology innovation, especially "new" enabling technology innovation, and the practical requirement of building a product are always present. Additionally, it is difficult to evaluate such challenges at an objective level and from an outside-in perspective of the entity, given that a governmental or funding agency is sponsoring product development. Thus, early identification of technical feasibility, the availability and maturity of necessary expertise, equipment and facilities resources, management model, governance practice, and finally, industry risks are strongly encouraged and required during the initiation and decision phase of product innovation. Other competitive technologies, geography, and regulatory influence also play a significant role in preliminary product evaluation. (Guiné et al., 2020)

Competitive benchmarking is the process of measuring products, services, and business models against those of the competition. The attributes used for comparison and evaluation are often chosen based on the type of products being compared. For example, an examination monitoring application should have real-time chat, notifications to ask a question in real time, and a customizable exam layout using a simple wizard. Requirements are also present in many, if not all, tools in competitive industries such as QA, aerospace, software development, etc. The process can also be employed for technical systems such as medical devices, as many states have specific requirements for products of this type. In these cases, it is also helpful to use competitor comparison as a method of identifying and selecting subjects for evaluating user validation through informal outside testing. (Lanzolla & Markides, 2021)

4.4. Heuristic Evaluation

The term "heuristics" was first introduced into design theory and practice by Jakob Nielsen, a Danish usability engineer and a prominent figure in website evaluation methods. Heuristic evaluation is a review of an interface (Wahyuningrum et al.2020). Experts such as usability designers use a small set of well-established usability principles, commonly referred to as heuristics, to identify problems in the design. The approach is based on the cognitive or psychological path that humans use when forming a judgment, in this case, a usability judgment. Heuristic evaluation is informal in nature and does not follow any procedures of human behavior. Experts in usability evaluate the product using minimal relevant surfaces of a user interface. (dos et al.2020)

A heuristic evaluation is a method for identifying design problems in a product. Evaluators judge the design against a set of guidelines (called heuristics) that make systems easy to use. (Lewis and Sauro2021). These heuristics act as guidelines for identifying potential usability issues and determining their severity. By conducting a heuristic evaluation, designers and developers can gain valuable insights into how a system can be improved to enhance user experiences. Additionally, this evaluation technique can be performed at different stages of the design process, enabling continuous improvement and refinement. Overall, heuristic evaluation serves as a valuable tool in creating user-friendly and intuitive interfaces (Aldoihi, 2020)

The purpose of heuristic evaluation is to identify areas of the product with fatal usability problems, generalize those areas, and suggest an appropriate course of action. At the individual level, heuristic evaluations provide mere suggestions from the perspective of the evaluator's expertise and experience, not that of the actual users. Researchers constructed a list of what they believed to be the most important heuristics in the field, based on the prominent heuristics of 15 usability professionals. Their list includes: visibility of system status, match between the system and the real world, user control and freedom, consistency and standards, error prevention, helping users recognize, diagnose and recover from errors, recognition rather than recall, flexibility and efficiency of user management, aesthetic and minimalist design, help and documentation. Empirical evidence shows that this technique can uncover 60-70% of usability problems with only three to five evaluators. Involving developers and usability professionals, some problems are identifiable, producing real-time results. (Baher et al., 2020)

6. Combined Evaluation Methods

- Mixed-Methods Approach
- Task Analysis
- Cognitive Walkthrough

This is called also Mixed-Methods Evaluation. There is a formal mixed-method evaluation technique referred to as potion use, presents, and derive. Potion uses and presents are described by Gaver from empirical observation of technology uses. The use takes place out in the real world while the presentation is in the laboratory. In a use study, scenarios are given to a subject who then makes their interpretations and uses of the device. In a presentation study, the researcher explains how the device works in its context and encourages interpretations of how the device works or other opinions before the subject using the device. Potion, derive, and focus groups use different variations of creative techniques to uncover and derive ideas of future products. Potion and focus groups each use 25 face-to-face interviews. The study used 15 different design disciplines in workshops to analyse and derive design ideas for new technologies working on new technology by using numerous role props and metaphors. (Airoma, 2020)

Mixed-method techniques are used to take advantage of the strengths of both quantitative and qualitative research methods to enable a richer insight and comprehensive view. Bates makes the point that evaluative research often requires "qualitative data (to tell you why) as well as quantitative data (to tell you how much)." This is particularly pertinent in the evaluation of the design of products where flexibility in the approach to gathering and triangulating research data is essential. There is a recognized anthropological survey method that uses both quantitative and qualitative techniques to measure the culture of an organization. An example of mixed-method evaluations are interactive evaluations or multi-method interviews. These are the only formal techniques to use real or prototype products in a requirements engineering environment. Their use of creatively designed questionnaires is unique. (Manzoor2020)

7. Emerging Trends

Design is a complex process, involving several iterations and decision-making stages, full of uncertainties and present knowledge. Technological advances and increased competition require better, more reliable and market-friendly innovative products. Both the quality of products and ways of working directly influence profitability and market growth. Continuous innovation is necessary, as well as strategies of rapid development, to make them feasible. (Baldassarre et al.2024)

7.1. On-Body Technologies

If we may categorize the technologies and demonstrate potential future applications with examples. The rapid growth in technology research and development creates new opportunities for qualitative evaluation of products, services, and quality of life. The applications are mainly driven by two trends – first, miniaturization, convergence, and functional innovation in electronic and sensor technologies; second, advances in visualization, data mining, decision support, and other software tools.

Hex dactiloscope for fingerprint image capturing. Invisible yet powerful electronic devices are now becoming pervasive in the form of RFID tags, which also include technologies like thin metallic antennas and embedded wired or battery-less sensors. The semipermeability of most non-metallic substances to high-frequency radio signals enables RFID tags and antennas to be enclosed or embedded within nontransparent media, including design materials for clothing, kitchen appliances, mattresses, wall paintings, embedded systems, food wrapping, and electronic labels for packaging applications. These body-antenna personal products are easily attached on or around the body for telecommunications purposes and for the personalized sensing of biological signals or fluid-based data from a subject.

Miniaturization in manufacturing and electronic technologies has been a big trend, especially since the invention of integrated circuits. In recent years, varying forms of it can be observed in LEDs, OLEDs, optical fibers, etc. They are enabling us to create very small but powerful optical and electronic devices.

7.2. Virtual Reality, Augmented Reality & AI

Virtual reality (VR) and augmented reality (AR) have already been used to optimize certain stages of the design process. These simulation techniques offer considerable advantages in the field of viewing, evaluation, and testing stages of product design. Unlike real models, such simulations are less demanding in terms of time, material, and human resources, allowing production teams to operate with fewer costs, thereby removing financial constraints during design phases. These powerful tools further support documentation and communication, which are critical in the overall design process. Through VR and AR simulations, the transfer of information flows more effectively, allowing direct operator participation in detail-level designing processes and enabling one to carry out continuous design-related modifications conforming to preliminary operator judgments. Such simulations produce vital hints that contribute to enhancing the product before starting mass production, and revisions are carried out according to real product users' opinions, thus fulfilling their expectations.

Generally, VR technology enables users of products, machines, and systems to experience them from a first-person perspective within a virtual realm, and it has been incorporated in three applications, namely head-mounted displays (HMD) like Oculus Rift and Samsung Gear VR, interactive projection techniques (IPT) such as CAVE automated virtual environment, and desktop installations. A second type of observation in VR is augmented reality, incorporating, for example, HMDs like Google Glass and Microsoft HoloLens, or also IPTs like autostereoscopic HTC Vive and non-stereoscopic metaio System. Especially during earlier steps in the design process, VR is a widely used method to evaluate interior and exterior car lines. Thereby, adaptation occurs as a real evaluation process but in a simulated environment. In the car industry, for various purposes/tests, computer-aided virtual reality systems are regularly used. These AR- or VR-based systems allow realistic three-dimensional viewing of, for example, a car or truck cabin in a virtual simulator. One specific VR-based ability is to experience and evaluate automotive or truck ride behavior, consisting of design evaluation and assessment of comfort.

Little research into this issue was found, so explicit

practical and applicative knowledge about the performance impacts and the contractual alternatives offered to the parties interested in the product and/or service, that is, the knowledge of when, what and who will do the use of mechanisms, as well as the performance impacts on the product and/or contractual alternatives and strategic alliances for a successful design project. (Verweij & van Meerkerk, 2021)

In this context, evaluations aimed at quality performance and market acceptance must be carried out throughout the product development process to ensure the success of the product before the target audience. These evaluations can be carried out through qualitative and/or quantitative product design evaluation methods and techniques. There are several innovation and design management models, with gradual managerial mechanisms, guided by the marketing and/or design approach, but little guidance for those who develop the products or services concerning the use of the identified evaluative mechanisms (Stylidis et al.2020).

7.2.1. Virtual Reality Testing

Virtual reality testing represents an advanced form of simulation. It provides compelling three-dimensional walk-throughs of design models before they reach the manufacturing stage. This virtual walk-through is useful to experience how a potential change will work and where it will have an impact. The advancement of virtual reality has also allowed serious analysis, especially human-in-the-loop testing (walking/moving within virtual reality). Psychophysiological testing is possible in the CAVE tissue. Despite the many advantages and promises that virtual reality holds, its development within manufacturing still lags in large-scale studies. The huge set-up costs associated with virtual reality may prevent widespread utilization. Likewise, expertise in the creation of virtual models is only really present in large businesses. The article presents a representative example of this latter point. Thirty-three per cent of automotive and aerospace industry designers report that potentially major modifications were not suggested during prototype assembly reviews because it was difficult to interpret the 2D drawings and visualization models. (Banga et al., 2022)

7.2.2. Augmented Reality Testing

In both practical and scholarly societies, several product design evaluation methods and techniques designed to help the designer receive comprehensive information concerning the five aspects in the product development stage have been developed. However, many of the current product design evaluation methods and techniques seem to lack consideration of their mutual complementarity or integration. Fortunately, the newest technique such as AR can provide service with compatibility of most of those existing evaluation methods and relevant information that are hard to provide through traditional techniques as well. (Sahu et al.2021)

Augmented reality (AR) service enriches the real world by intelligent interaction. Therefore, AR techniques can provide real-time evaluation services for product design, which can increase accuracy and instantaneity. An AR-based evaluation process of a newly designed exhibit is presented in this paper, which contains image presentation, human gestures capturing, image processing, 3-D object showing, and report-making and result storage. The designed system can guide the AR designer and AR design evaluation practitioner to promote the product design and supplement their expertise. (Cascini et al.2020)

7.2.3. AI and Machine Learning

By analyzing feedback associated with user preferences and acceptance for physical objects and using them to adjust the industrial designer's intuition, AI systems may provide a solid design analytics tool for large-scale manufacturing companies. In addition, implemented systems are suitable for an open discussion of the design idea and its development with a larger audience by exposing the user feedback channels. The various forms of feedback and the fact that these are available to participants within an Augmented Reality (AR) experience may encourage the participants to engage more deeply in the design review and amendment process.

Applications of AI in qualitative evaluation might consist of involvement of chatbots, hybrid conversational interfaces, or sensory-rich virtual environments, automated sentiment analysis, and automatic advice or tutoring. In particular, machine learning techniques working on accessible sensory signals, such as natural language generation, understanding of human voice, or visual feedback, promise a significant reduction in development effort, an increase in consideration of user diversity, and scalability.

AI technologies enable automatic speech recognition, natural language understanding and generation, and image processing. This makes applying methods feasible that were previously restricted to a few expert specialists, are seldom used at the polytechnical evaluation stage, present alone or in smaller research groups, and depend on sound empirical data on user feedback and acceptance.

AI technologies and, in particular, machine learning techniques are increasingly applied for qualitative evaluation tasks. On one hand, the rise of digital technology, the increasingly available computing power, storage, and internet capacity leads to a plethora of possible new data sources that may feed into traditional research topics or emerge completely new topics. On the other hand, machine learning techniques have made impressive progress in architectural and scalability terms during recent years.

8. Ethical Considerations in Evaluation

However, guidelines for conducting empirical product design evaluations, such as qualitative interviews with key informants, have fallen short. "Sound" research should be characterized as research promoting consistency, honest inquiries, maintaining confidentiality, quality, and developing sensitivity while designing compensation plans to ease potential negative implications. Interviews with designers, engineers, and participants, in particular, discussing design aspects related to expectations, emotions, and the interaction between the product and all family systems represent a unique challenge. It can be assumed that, in the case of innovative items, even more implications are put into

play, as these have the potential to bring significant impact on daily life dynamics. Identifying specific ethical implications in this literature review inspires additional conscientious engagement and contributes to the raising of awareness among researchers.

Ethical concerns can arise in many stages of empirical research. The issue of ethics with regard to qualitative approaches and the degree of guidance researchers can provide to ensure a higher ethical standard is a continuous topic of discussion. When it comes to the empirical evaluation of product design, ethical concerns that influence the general conductance of qualitative interviews have been discussed, such as the preference to conduct male-female interviewees, working hours directly associated with housework or other roles, gender biases and inequalities within the couple, and the issue of power dynamics, dialogue formation, misunderstandings, disengagement, and participation in a conversation.

9. Case Studies

The study of Llopis-Albert et al.2021 illustrates the potential of some of the techniques mentioned, a simple case study has been applied in the industry of the comparative testing of product designs. After showing the application of each technique, conclusions were drawn as to which design was chosen as the best option to further modify for the manufacturing stage. Several other different methods and techniques have been reviewed by (Sahin, 2024) that can be used in the evaluation stage to discard potentially poor design solutions and to determine which design is the best option for the best cost. The review of the above case studies is concentrated on understanding methodologies. Unlike many research documents in human factors and ergonomics, which not only propose methods but also have practical applications, those that have seen the light of day in industry are rare. (Usuga et al.2020). However, all these studies had a common subject: first, the design, creation, or acquisition of evaluation methods in connection with ongoing design tasks; second, the training of people responsible for using these methods. (Pohl et al.2020) The current study presents in more details two case studies; one from apple and the other from an Egyptian educational product design institution.

9.1. Apple's Design Process

To survive in such a rapidly changing market, the company should dare a lot, establish and question paradigms. From monsters in sales like Nokia and Research in Motion (RIM), the market of portable communication suddenly changed. It is interesting to note that behind Apple products, Steve Jobs worked with, the product designer Jony Ive (number two in the company). In an interview, Jobs said, "Since the designers work at the same place, they are friends, they develop a knowledge that belongs only to them. I do not see what some might consider a conflict. This is the way I imagine that a great artist would get along with other talented people in a band, for example." Jony Ive takes high praise for carrying out concepts of minimalism and essentialism in Apple products, (Rowlett, 2020). Many times, for example, in an iPod briefing, Jobs said that he wanted to put one more button and Ive replied, "What does the button do?" and Jobs had no answer. Without further comment, Ive begins a series of studies on the shape and operation of the device until it is free of any one more unnecessary button. (Rowlett, 2020)

According to Walter Isaacson, Apple's founder, Steve Jobs was hypercritical of Apple products. "I care about creating great products, not being the wealthiest company in the cemetery," said Jobs. Despite his hypercritical view of the products, Jobs was convinced that design cannot be done by a committee, only a single person. Several Apple products combine many functions in just one. The iPod, for example, was simply a music player combined with a portable hard disk. It was a great innovation in itself. But Apple added that it would be a telephone and people started to dream of having a high-quality camera... When daringly Jobs communicated that Apple would have a cell phone, he meant the iPhone, a huge device with real fun in using it. People say that at that time the standard phone had about 80 buttons, and Jobs demanded that Apple's phone be a simple one: round in shape, the device was operated by a single front button. Everybody knows what happened then. (Kim, 2020)

Figure () Image illustrating Apple products evaluation

9.2. Kitchen Appliances VR Evaluation

In this quasi-experimental study an attempt has been made to use an Oculus Rift device to design and evaluate several product designs. The experiment included six individuals (three experienced academic designers and three product design students). The Oculus Rift device. The goal here was simply to use the VR for evaluating each design step and estimate how the VR experience was valuable in providing significant design data or

reports. It was clear that the idea itself was new to everyone, as although some of the participants had used virtual reality devices for some purpose before, all of them were not accustomed to or practiced design or even aspects of it using this new technology. In the experiment, the product was displayed from all its angles, and it was also learned how to open and close it and the control processes associated with it, from unscrewing the Power Cable wire to turning on the power, etc. In addition to signs and indicators. Then the designer made a number of attempts to reduce and enlarge the size of parts of the product and the subsequent change in other parts automatically. The experiment included training on the skills of exposing the product, whether in wireframe form or in a Fully Rendered Product. The product was displayed from all its angles, and many other functional uses of the product were practices. Designer made a number of attempts to evaluate convenience the size of the product by reducing and enlarging the size of different components of the product and the subsequent change in other parts automatically. (Sama Waheed 2021)

Figure () Images from an Egyptian case study (Sama Waheed 2021)

10. Challenges and Limitations

It is important to understand the broader context and to formulate a comprehensive portfolio of evaluation methods and techniques that are tailored to address the diversity of design issues. Membership of appropriate individuals with appropriate backgrounds, experience, and expertise is a critical factor. Despite the existence of product design evaluation methods, it is still often made in an ad hoc and unstructured manner, which can make it difficult to compare, refine, critique, and learn from evaluation activities and experiences. It is possible to state that theoretically, it is possible to develop, test, deploy, and learn from a diverse set of product design evaluation methods and techniques. (McCaffery et al.2020)

The evaluation of ideas and concepts in product design through methods and techniques seems simple but is, in fact, not straightforward. With innovation and the diversity of product design issues, some particular challenges need to be overcome. The main challenge is related to the three foundations of the evaluation: quality or impact, flexibility, and completeness. This last foundation is fundamental due to the multidisciplinary nature of the evaluation procedures, and many methods and techniques proposed are focused on one single domain and cannot be used in a multidisciplinary environment. The plurality of hierarchical levels and objectives, as well as the degree of synthesis, also need to be approached in detail. Additionally, questions related to factors that may cause the evaluation to fail are very important to identify. (Bommasani et al.2021)

Sample Size and Representativeness is a major challenge. Some limitations in sampling hinder the deliverance of complete attribute representation, resulting in the reduction of the number of samples under evaluation. This issue is closely related to the efficiency of information management systems, which are accounted to be the most significant technological factor influencing the efficiency of the innovation process throughout the global economy in the last decade. In addition, product evaluations are made in practice not only through immediate use but also through several quick and architectural models built. In the first case, only some limited design properties are evaluated, and in the second case, the accuracy and the difficulty for the derived multiple attribute model depend strongly on how well the simplified designs obtained from the simplifications have preserved principal characteristics from the actual design. (Chazette & Schneider, 2020)

The completeness of the representation obtained through sampling from the domain of a population defines the representativeness of this sample. The size of the sample usually defines how well it was conducted. These two issues are, of course, interrelated. However, it is not easy to satisfactorily answer the two basic questions of how many of the product attributes will be included in the sampling, and how much the results of product evaluations are valuable for the whole design process. In most cases, the design problems requiring design product evaluation parameters are confronted with a variety of sources of information that have a high impact on the way the required information is obtained. Moreover, practical difficulties raise questions of how to explore a high quantity of design product evaluations from different sources of information and production methods with minimal effort. (Hennink & Kaiser, 2022)

The number of users of a product often necessitates thinking about the various ways in which cultural or geographical differences may affect our evaluation techniques. (Lee et al., 2020) Carefully review your audience and your user database before trying to apply your form outside the geographic scale for which it was intended. (Zhang and Dong2020) Different languages can use totally different words to refer to things with different shapes.

11. Conclusion and Future Directions

Product design or evaluation has become increasingly vulnerable to technological and environmental changes and competition. As a result, it has become one of the most important features of a product. Product design

evaluation can judge the design qualitatively and quantitatively by comparing the design with the requirements expected to be clear, reasonable, feasible, and possible gradation, and to assess the relevant factors which can have an impact on the product design in the design stage or supply chain. Different methodologies have been introduced to provide product designers with guidelines on aesthetics, shape, ergonomics, colour, material, quality, etc., with not only one criterion but many evaluation criteria. In this paper, an overview of the existing evaluation methods and techniques was reviewed to shed light on the current state of research in product design evaluation. Future directions for evaluation research are also discussed in this paper to provide a better BPM system. (Leavy, 2022)

In today's competitive world of business, product design engineers are called upon to deliver innovative and exciting consumer goods to meet corporate and marketing strategic objectives. They are faced with many different and conflicting challenges. Their job is not an easy one, as they must marry design to manufacturing economics and meet the target build and bill of materials costs. They must also have a deep understanding of the social and ecological implications of their design. To help the development of new product design evaluation tools to assist in the strategic nature of their work, engineering functional analysis trainers and survey tools, in concert with database management systems, have begun to be developed. They will help the engineer to be able to create value-added products with strategic advantage. (Cross, 2021)

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