Mix Sustentável

Modular smartphones as a sustainable alternative: the role of product design in the face of obsolescence

Modular smartphones as a sustainable alternative: the role of product design in the face of obsolescence

Los smartphones modulares como alternativa sostenible: el papel del diseño de productos frente a la obsolescencia

José Lucas Pereira Mendes[1]
Bárbara Tatiele Santos[1]
Jocelise J. Jacques[1]
Léia Miotto Bruscatto[1]

[1] Universidade Federal do Rio Granda do Sul, Departamento de Arquitetura e Urbanismo, PósARQ - Programa de Pós-graduação em Design, Universidade Federal do Rio Granda do Sul, Porto Alegre, Brasil

Correspondência para: barbara.santos.designer@gmail.com

Resumo: O avanço acelerado da tecnologia e os padrões atuais de consumo têm intensificado os impactos ambientais associados à obsolescência dos dispositivos eletrônicos. Nesse contexto, o design de produto sustentável emerge como ferramenta estratégica para ampliar a vida útil dos bens de consumo e estimular práticas de reparabilidade e reuso. Este estudo discute o papel do designer frente a esses desafios, analisando as possibilidades oferecidas pelos smartphones modulares, inspirados no conceito Phonebloks. A pesquisa evidencia como a modularidade pode favorecer a personalização e reduzir o volume de resíduos

ARTIGO ORIGINAL - SEÇÃO CIENTÍFICA

Editor responsável pelo artigo: Lisiane Ilha Librelotto, Dr. Eng., Paulo Cesar Machado Ferroli, Dr. Eng.

Recebido em
24/12/2025
Aprovado em
12/01/2026
Publicado em
13/01/2026

PID
10.29183/2447-3073.MIX2025.v11.n3.68-82

eletrônicos, mas também aponta as barreiras econômicas e culturais que dificultam sua adoção em larga escala. Os resultados destacam a necessidade de maior integração entre inovação tecnológica, responsabilidade projetual e engajamento dos consumidores, de modo a consolidar alternativas viáveis para o design sustentável.

Palavras-chave: Modular smartphones as a sustainable alternative: the role of product design in the face of obsolescence

Abstract: The rapid advancement of technology and current consumption patterns have intensified the environmental impacts associated with the obsolescence of electronic devices. In this context, sustainable product design emerges as a strategic tool to extend the lifespan of consumer goods and encourage repairability and reuse practices. This study discusses the role of the designer in the face of these challenges, analyzing the possibilities offered by modular smartphones, inspired by the Phonebloks concept. The research highlights how modularity can favor personalization and reduce the volume of electronic waste, but also points to the economic and cultural barriers that hinder its widespread adoption. The results emphasize the need for greater integration between technological innovation, design responsibility, and consumer engagement, in order to consolidate viable alternatives for sustainable design.

Keywords: Modular smartphones; Planned obsolescence; Sustainable product design; Technology and sustainability; Design innovation

Resumen: El rápido avance de la tecnología y los patrones actuales de consumo han intensificado los impactos ambientales asociados a la obsolescencia de los dispositivos electrónicos. En este contexto, el diseño sostenible de productos surge como una herramienta estratégica para extender la vida útil de los bienes de consumo y fomentar prácticas de reparabilidad y reutilización. Este estudio discute el papel del diseñador frente a estos desafíos, analizando las posibilidades que ofrecen los smartphones modulares, inspirados en el concepto Phonebloks. La investigación destaca cómo la modularidad puede favorecer la personalización y reducir el volumen de residuos electrónicos, pero también señala las barreras económicas y culturales que dificultan su adopción a gran escala. Los resultados enfatizan la necesidad de una mayor integración entre la innovación tecnológica, la responsabilidad del diseño y la participación del consumidor, con el fin de consolidar alternativas viables para el diseño sostenible.

Palabras clave: Smartphones modulares; Obsolescencia programada; Diseño

Contribuição dos autores segundo a Taxonomia CRediT

Prezados autores, Solicitamos declarar a forma de contribuição nesse manuscrito de cada autor segundo a Taxonomia CRediT (http://credit.niso.org/). Nomear autores envolvidos em cada tipo de contribuição, deixar em branco não havendo uma contribuição específica. Nomear pela sigla do nome do autor. Exemplo: Sigla dos autores: Autor 1: José Lucas Pereira Mendes, JLPM Autor 2: Bárbara Tatiele Santos, BTS Autor 3: Jocelise Jacques de Jacques, JJJ Autor 4: Léia Miotto Bruscatto, LMB

JLPM: conceptualization, investigation, methodology, formal analysis, and writing – original draft.

BTS: investigation, methodology, formal analysis, and writing – original draft.

JJJ: writing – review, editing and validation.

LMB: supervision, project

sostenible de productos; Tecnología y sostenibilidad; Innovación en diseño

Como citar: MENDES, José Lucas Pereira; SANTOS, Bárbara Tatiele; JACQUES, Jocelise J.; BRUSCATTO, Léia Miotto. Modular smartphones as a sustainable alternative: the role of product design in the face of obsolescence. **Nome da Revista**, Cidade, v. xx, n. xx, p. x-xx, 2025. DOI: https://doi.org/10.29183/2447-3073.MIX2025.v11.n3.68-82.

administration, resources, and writing – review, editing.

Conflito de interesses

Declaração de conflitos de interesse: os autores declaram não haver conflitos de interesse.

Fonte de financiamento

Fonte de financiamento: Coordination for the Improvement of Higher Education Personnel – Brazil (CAPES).

1 INTRODUCTION

The accelerated disposal of electronic devices, especially smartphones, is one of the main current environmental challenges. In 2022, 62 million tons of electronic waste (e-waste) were generated globally, of which only 22.3% were correctly collected and recycled, showing that the generation of electronic waste is growing almost five times faster than its recycling (Baldé *et al.*, 2024) (World Health Organization, 2024). These numbers reinforce the urgent need for more circular consumption and production strategies, aligned with environmental preservation.

In this scenario, sustainable design assumes an essential role by integrating environmental, social, and economic aspects into product design, seeking to extend its durability and mitigate impacts throughout its life cycle (Pazmino, 2007).

Practices such as planned obsolescence, characterized by the intentional reduction of product lifespan, and perceived obsolescence, related to symbolic or aesthetic obsolescence, accelerate the premature disposal of electronic devices and amplify the environmental impacts associated with their production and disposal cycle (Santos; Guarnieri; Streit, 2021). This dynamic especially affects smartphones, whose renewal cycle is among the shortest in the technology industry.

Recent research highlights modularity as a promising alternative to extend the lifespan of electronic devices. Goodwin *et al.* (2023) analyze the usefulness of devices considered obsolete and the obstacles faced for their continued functionality, while Gould, Song e Zhu (2024) highlight the economic and environmental impacts of technological device obsolescence. These discussions reinforce the potential of product design as an instrument to stimulate repairability practices and promote sustainable solutions.

Starting from this debate, this article proposes a critical analysis of the role of the product designer in the face of obsolescence, focusing on modular smartphones as a sustainable alternative. The objective is to highlight how modularity can favor more responsible consumption models and solutions aligned with the logic of the circular economy.

2 THEORETICAL CONTEXT

Theoretical contextualization is fundamental to understanding the relationship between sustainable product design and the problem of obsolescence in electronic devices. Design, when guided by sustainability principles, must integrate social, economic, and environmental aspects into the design process, seeking not only to meet market demands but also to reduce negative impacts throughout the product lifecycle (Pazmino, 2007) (Mendes, 2022).

The designer's responsibility, in this sense, goes beyond aesthetic or functional aspects: it involves proposing solutions that promote durability, repairability, and reverse logistics, aligning with the guidelines of the circular economy (Magera, 2013) (Baldé *et al.*, 2024).

However, the consolidation of such practices faces challenges posed by planned obsolescence, characterized by the intentional planning of reducing the useful life of products, and by perceived obsolescence, related to the perception of symbolic or aesthetic obsolescence, even when the product remains functional (Santos; Guarnieri; Streit, 2021). Both forms intensify premature disposal, especially in the smartphone sector, where technological and market renewal is accelerated.

In this way, understanding the impacts of obsolescence becomes essential so that sustainable product design can be effectively applied as a tool for transformation, stimulating more conscious consumption patterns and contributing to the reduction of electronic waste generation (Goodwin *et al.*, 2023) (Gould; Song; Zhu, 2024).

2.1 Product design and its responsibility in sustainability

Product design plays a strategic role in the transition to more sustainable consumption models, especially in sectors with high technological turnover, such as smartphones. Unlike a view restricted to aesthetics or immediate functionality, sustainable design seeks to integrate environmental, social, and economic concerns at all stages of the product lifecycle (Pazmino, 2007). This implies considering everything from the choice of materials to disposal, promoting solutions that favor durability, repairability, and reuse.

In the context of mobile devices, this responsibility becomes even more relevant given the impact of planned and perceived obsolescence, which accelerates the disposal of devices and increases the generation of electronic waste (Lopes, 2022). Designing smartphones that allow for accessible maintenance, component upgrades, and a longer lifespan therefore becomes a concrete way to mitigate these effects. Modularity presents itself as a promising alternative in this scenario, as it allows parts of the device to be replaced or upgraded without the need to replace the entire product, reducing pressure on natural resources and encouraging circular economy practices (Mendes, 2022).

Thus, by opting for strategies that incorporate modular logic, design acts as an agent of transformation not only at the technical level, but also at the cultural level, encouraging consumers to rethink their relationship with electronic devices. The commitment to sustainability, in this sense, transcends the design dimension, reflecting a collective effort to balance technological innovation and socio-environmental responsibility.

2.2 Planned obsolescence and perceived obsolescence

Planned obsolescence and perceived obsolescence are two of the main forces that accelerate the disposal of smartphones and increase the generation of electronic waste, hindering the development of practices aligned with sustainability. The first is related to design strategies that deliberately reduce the lifespan of a product, while the second refers to the consumer's perception that a particular device has become outdated, even if it remains fully functional (Santos; Guarnieri; Streit, 2021).

In the field of product design, these two types of obsolescence reveal the impact of design decisions on the relationship between users and technology. The non-replaceable battery is a classic example of planned obsolescence: when battery life begins to fail, the consumer is often forced to replace the entire device, even if the other components remain in good condition. Similarly, the interruption of software updates by manufacturers contributes to making older models vulnerable to security flaws and incompatible with new applications, forcing the purchase of new devices.

Perceived obsolescence manifests itself mainly in aesthetic and symbolic aspects. Designs considered "outdated"or intense exposure to marketing campaigns that extol the attributes of newer models—such as improved cameras or larger screens—lead consumers to believe that their devices no longer meet their needs, even if they function adequately.

This scenario highlights how design, while it can reinforce accelerated consumption practices, also has the capacity to propose alternatives. The adoption of modularity, for example, can reduce the dependence on frequent replacements by allowing specific parts of the smartphone to be updated or repaired individually, mitigating both planned and perceived obsolescence.

2.3 Electronic waste and the role of modular design.

Electronic waste is one of the biggest contemporary environmental concerns, driven by accelerated consumption and the rapid replacement of electronic devices. In Brazil, the scenario is alarming: the country leads the generation of electronic waste in Latin America and occupies the fifth position worldwide, with approximately 2.1 million tons discarded annually. However, less than 3% of this volume is properly recycled, which exposes weaknesses in the reverse logistics infrastructure and management mechanisms foreseen by the National Solid Waste Policy (PNRS) (Brasil, 2022) (Magera, 2013).

Among the main factors exacerbating the problem is obsolescence, both planned and perceived, which artificially reduces the lifespan of products and encourages the frequent acquisition of new devices (Santos; Guarnieri; Streit, 2021). Smartphones, in particular, have become symbols of this accelerated consumption cycle, accumulating significant impacts due to the presence of heavy metals such as lead, mercury, and cadmium, which represent environmental and human health risks. Furthermore, improper disposal compromises the recovery of high-value materials such as gold, copper, and silver, limiting opportunities for reuse.

In this context, product design plays a crucial role in proposing solutions capable of reducing pressure on the environment. Modularity, for example, emerges as an alternative to mitigate the challenges of electronic waste, as it allows individual components to be replaced, repaired, or upgraded without the need to discard the entire device (Mendes, 2022). This design logic contributes not only to extending the lifespan of devices but also to fostering a circular economy, reducing the extraction of natural resources and the generation of waste.

Therefore, tackling the challenges of electronic waste requires not only robust public policies and greater consumer awareness, but also a strategic approach to product design in building innovative solutions that reconcile technological advancement and environmental responsibility.

2.4 The smartphone lifecycle and modularity as an alternative.

The life cycle of electronic devices is a critical point in the sustainability debate, especially due to the environmental impact generated at each stage, from the extraction of raw materials to final disposal. In the predominant linear model, products are manufactured, consumed, and quickly discarded, resulting in large volumes of electronic waste and the intensive exploitation of natural resources (Magera, 2013). This logic reflects design and production practices that, historically, have given little consideration to the reuse of materials and the possibility of extending the lifespan of devices.

The introduction of concepts related to sustainable design and the circular economy seeks to modify this paradigm, proposing a model in which products are designed for reuse, repair, recycling, and repurposing (Pazmino, 2007). However, the presence of planned and perceived obsolescence strategies still represents a significant obstacle, since it encourages consumers to replace devices before the end of their useful life (Santos; Guarnieri; Streit, 2021).

In the case of smartphones, this linear cycle becomes even more evident due to their rapid technological obsolescence and the constant appeal for new models. Modularity, however, emerges as an alternative capable of redefining this cycle, allowing individual components—such as battery, camera, or processor—to be replaced or upgraded independently, without the need to discard the entire device (Mendes, 2022). This approach reduces resource extraction, favors the reuse of materials, and allows for greater recovery of components at the end of their useful life.

Thus, understanding the smartphone lifecycle from a modularity perspective means recognizing the potential of product design to reverse linear practices and bring the electronics sector closer to a circular logic. Beyond technical solutions, this change also requires effective public policies and consumers willing to adopt more conscious usage habits (Oliveira; Santos, 2022). In this way, modular design not only contributes to minimizing environmental impacts but also strengthens the link between technological innovation and socio-environmental responsibility.

3 MODULAR SMARTPHONES: SUSTAINABLE INITIATIVES AND IMPACTS

This section analyzes relevant initiatives in the development of modular smartphones, highlighting how modular design can extend product lifecycles, reduce electronic waste, and promote sustainable practices. Conceptual and commercial examples are presented: Phonebloks, Project Ara, Fairphone, and Shiftphone, highlighting convergences and challenges in terms of modularity, sustainability, and market adoption.

3.1 Phoneblocks

Phonebloks, created by Dave Hakkens in 2013, is a pioneering modular smartphone concept developed with the goal of reducing the environmental impact caused by the disposal of electronic devices (Hankammer *et al.*, 2016). The proposal is based on the creation of a phone composed of interchangeable blocks, allowing the user to replace individual components—such as the camera, battery, or processor—without having to discard the entire device.

In addition to enabling repairability, the model encourages customization, since each consumer can adapt the device to their specific needs, prioritizing, for example, greater battery life or better photographic performance. This flexibility makes the concept not only functional, but also aligned with the principles of sustainable design, by extending the product's life cycle and reducing material waste.

Figura 1 – The concept of modular cell phone

Source: Mendes (2022).

Although Phonebloks was never commercially produced, the project gained widespread attention and

inspired relevant discussions about modularity and sustainability in product design (Mendes, 2022). Its innovative proposal caught the attention of the market and consumers by challenging the logic of planned obsolescence and introducing a new way of thinking about the life cycle of electronic devices.

The idea of a modular smartphone, capable of having its components individually replaced, inspired concrete projects such as the Fairphone and the Shiftphone, which sought to apply the same principles of repairability and customization (Hankammer *et al.*, 2016). The positive reception of the concept highlighted a growing demand for more responsible technological solutions, leading consumers to question the linear consumption model in which products are quickly discarded due to lack of maintenance or updates (Santos; Guarnieri; Streit, 2021).

In this context, Fairphone established itself as one of the first commercial attempts to combine modularity and production ethics, while Shiftphone sought to democratize access to this type of technology, betting on a simpler and more accessible approach (Gomez, 2024).

Despite this initial impact, the resistance of large corporations to incorporating modularity made the difficulties of the Phonebloks model clear. For Mendes (2022), modular design challenges the dominant economic model, sustained by planned obsolescence and the constant renewal of products. The possibility of upgrading and replacing parts reduces the demand for new devices, which discourages adoption by traditional manufacturers.

Furthermore, technical and financial challenges have also proven significant. Gupta, Panda e Raina (2018) point out that the creation of interchangeable modules demands rigorous technological standardization and high investments in research and development. From the consumer's perspective, Oliveira e Santos (2022) highlight that many still prioritize aesthetics and immediate performance over durability or sustainable practices.

On the other hand, the concept spurred a relevant debate about the role of companies and users in reducing electronic waste. According to Magera (2013), tools such as reverse logistics and sustainable design are fundamental to reducing environmental impacts, but still face barriers due to a lack of incentive policies and regulations. From this perspective, Phonebloks broadened the reflection on the need to integrate principles of circular economy and sustainability into product design (Pazmino, 2007).

In summary, although the adoption of the modular model faced technical, economic, and market obstacles, Phonebloks left an important legacy by inspiring projects such as Fairphone and Shiftphone and by questioning conventional industry practices. Its impact remains a landmark in the debate on innovation, repairability, and sustainability in the electronics sector.

3.1.1 Ara Project

Launched by Google in 2013, Project Ara emerged as a proposal inspired by the Phonebloks concept, with the intention of developing an open and modular platform for smartphones.

The central idea was to allow the user to adapt and extend the lifespan of the device by replacing indi-

Figura 2 – The concept of modular cell phone

Source: Mendes (2022).

vidual modules such as the battery, camera, or processor instead of discarding the device entirely (Hankammer *et al.*, 2016). The structural base of Ara consisted of a skeleton that connected the modules through magnetic snap-fit and fastening systems, providing configuration flexibility and greater autonomy to the consumer. This proposal sought not only customization but also the reduction of electronic waste and the extension of the product lifecycle (Gupta; Panda; Raina, 2018).

Despite initial enthusiasm, the project faced considerable barriers. Among these were the technical difficulties in standardizing fully interchangeable modules and the low engagement of major manufacturers in the sector, unwilling to abandon business models based on rapid and constant updates. In 2016, Google officially announced the end of the initiative, marking the end of one of the most daring experiments in the field of modular smartphones. Even so, the legacy of Project Ara remains relevant in demonstrating the viability and obstacles of integrating modularity as a strategy to combat planned obsolescence and encourage more sustainable design practices.

3.1.2 Fairphone

The Fairphone emerged in 2013, developed by the Dutch company of the same name, with the aim of offering a modular smartphone that combined ethics and sustainability in a single product. Unlike concepts such

as Phonebloks and Project Ara, the Fairphone was effectively launched on the market, becoming a practical example of the application of modularity in the design of mobile devices (Gomez, 2024).

The project prioritizes the repairability and replacement of essential parts, such as the battery, screen, and camera, in order to extend the device's lifespan and reduce premature disposal. Furthermore, the company stands out for its social and environmental responsibility in its production chain, using recycled materials and minerals from more responsible sources.

Recognized as a milestone in the field of sustainable design, the Fairphone proves that it is feasible to reconcile commercial objectives with environmental and social responsibility. Its trajectory reinforces modularity as an essential tool to combat planned obsolescence and contribute to the reduction of electronic waste.

3.1.3 Shiftphone

The Shiftphone, developed by the German company Shift GmbH, represents another relevant initiative in the field of modular smartphones. Like the Fairphone, the project focuses on sustainability and repairability, but it differs by emphasizing design simplicity and accessibility in the repair process (Gomez, 2024).

The Shiftphone aims to allow any user, even without advanced technical skills, to replace modules or perform basic repairs independently. Furthermore, the company adopts a transparent approach in its production chain, prioritizing the use of recyclable materials and ensuring ethical working conditions. Although it has not yet achieved the same notoriety as the Fairphone, the Shiftphone contributes significantly to the debate surrounding modularity and sustainability. Its existence demonstrates the viability of alternative models that prioritize both the consumer and the environment, directly challenging the traditional logic of production and disposal of electronic devices.

4 DISCUSSION

Based on the experience of Project Ara and the Phonebloks concept, it becomes inevitable to reflect on the possibilities and limitations of sustainable design in the current scenario. As Mendes (2022) points out, the discussion goes beyond the technical dimension and reaches the ethical and social field, raising fundamental questions: to what extent would it be feasible to design most of our artifacts following principles of modularity and repairability? What are the reasons why a large part of the industry insists on monobloc models, which make the replacement of a single component difficult and expensive, encouraging the premature disposal of entire products? And, furthermore, why have environmental policies and regulations not been sufficiently effective in curbing practices such as planned obsolescence and the lack of accessible repair options?

An analysis of these issues reveals two central fronts. On the one hand, there are barriers imposed by the very logic of the market, in which profit is sustained by the constant renewal of products, a practice that contradicts the principles of modularity. On the other hand, there is a noticeable absence of robust public

policies capable of encouraging or even obligating companies to adopt more sustainable design and production strategies. In this sense, the lack of specific regulations on repairability and durability keeps consumers hostage to a linear model, in which obsolescence and disposal are still the rule.

Despite these barriers, design has transformative potential, as it is through design that more durable, repairable alternatives aligned with the circular economy can be introduced. Furthermore, when combined with consumer awareness initiatives and the strengthening of reverse logistics, sustainable design can not only mitigate environmental impacts but also influence changes in purchasing and usage behavior. Thus, this chapter seeks to discuss precisely this paradox: while industry resists modularity due to economic and cultural factors, design presents itself as a strategic tool for rethinking consumption patterns and paving the way for more responsible and circular practices.

4.1 Barriers to implementing sustainable designs

The implementation of sustainable and modular projects still faces strong resistance from the industry. As Padilha e Bonifácio (2016) point out, the prevailing market logic relies on planned obsolescence, which creates products with intentionally reduced lifespans to stimulate continuous consumption. Modularity breaks with this model, as it allows for repairs and upgrades, reducing the need for frequent replacements and, consequently, impacting company profits. Beyond the economic aspect, there are technical and structural obstacles. According to Ribeiro, Rezende e Franco (2021), the manufacture of modular devices requires greater investment, both in standardization and in research and development, increasing the complexity of production. Another critical point is reverse logistics, which (Magera, 2013) points out as insufficient in many contexts, hindering the reintegration of components into the production cycle. Consumer behavior also plays a role: according to Oliveira e Santos (2022), criteria such as aesthetics, immediate performance and technological innovation still prevail over concerns about durability, which reinforces the preference for disposable and rapidly obsolete products.

4.2 Design and its potential to influence consumer habits.

Although the challenges are significant, sustainable design stands out as an essential tool for transforming consumption patterns. Mendes (2022) argues that design practice can not only extend the lifespan of products, but also promote cultural changes, encouraging consumers to adopt more responsible behaviors.

Examples such as Fairphone and Shiftphone demonstrate this potential by combining repairability, modularity, and ethical production practices. These initiatives offer concrete alternatives to the traditional model, encouraging choices that prioritize durability and reduced environmental impact instead of impulsive consumption (Gomez, 2024). However, for this change to be consolidated, public policies are fundamental. As Magera (2013) reinforces, regulatory mechanisms—such as the taxation of non-repairable products, tax incentives for

modular solutions, and effective reverse logistics systems—can drive the adoption of more sustainable practices.

Finally, sustainable design transcends the technical dimension, also constituting a social and cultural practice. According to Pazmino (2007), approaches such as eco-design and social design can redefine the relationship between consumers and products, favoring more ethical and conscious consumption aligned with the principles of the circular economy.

5 CONCLUSION

This article analyzed the potential of sustainable design as a transformative tool in the face of the challenges of planned obsolescence and perceived obsolescence, focusing on case studies such as Phonebloks, Project Ara, Fairphone, and Shiftphone. From this review, it was possible to identify significant advances in modularity, repairability, and social responsibility, as well as structural barriers that hinder the diffusion of these practices in the global smartphone market.

The industry's resistance to adopting modular and sustainable designs is related to economic, technical, and cultural factors, including the prioritization of monobloc models, high modular production costs, module standardization, and marketing strategies that encourage accelerated consumption. However, examples such as Fairphone and Shiftphone demonstrate that it is possible to reconcile technological innovation, repairability, and ethical production practices, offering concrete alternatives to the predominant linear model.

Beyond its technical impact, sustainable design plays an ethical and political role, influencing consumer behavior and strengthening the social responsibility of both companies and consumers. The product designer, therefore, acts as a transformative agent, proposing solutions that not only extend the lifespan of devices but also promote environmental awareness and more responsible consumption practices.

To consolidate these changes, it is essential to strengthen public policies that encourage modularity, repairability, and the right to repair, as well as the implementation of efficient reverse logistics systems. Additionally, consumer education campaigns can raise awareness about environmental impacts, stimulating more ethical and sustainable choices.

Finally, future studies could explore metrics to assess the environmental and social impact of modular smartphones, the economic viability of circular business models, and the integration of public policy and sustainable design in different national contexts.

Thus, the legacy of Phonebloks and its developments transcends commercial results, establishing itself as a conceptual reference for balancing technological innovation, ethics, and environmental responsibility, pointing to concrete paths towards a more conscious and sustainable future.

REFERÊNCIAS

Baldé, C. P. *et al.* **The Global E-waste Monitor 2024: quantities, flows and the circular economy potential**. Bonn; Geneva: International Telecommunication Union and United Nations Institute for Training and Research, 2024.

Brasil. **Política Nacional de Resíduos Sólidos (PNRS)**. 2022. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. Disponível em: <https://www.gov.br/ibama/pt-br/assuntos/emissoes-e-residuos/residuos/politica-nacional-de-residuos-solidos-pnrs>.

Gomez, R. T. **From disposability to conviviality: investigating planned obsolescence and modular smartphone design**. 2024. 105 p. Dissertação (Mestrado) — University of Twente, Enschede, 2024. Disponível em: <https://essay.utwente.nl/essays/102884>.

Goodwin, C. *et al.* Quantifying device usefulness: how useful is an obsolete device? In: **INTERACT 2023 - Human-Computer Interaction**. Cham: Springer Nature, 2023.

Gould, P.; Song, G.; Zhu, T. **Environmental and economic impact of I/O device obsolescence**. 2024. ArXiv preprint. Disponível em: <https://arxiv.org/abs/2412.20655>.

Gupta, S. K.; Panda, D. P.; Raina, C. K. Google project ara. **International Journal of Advance Research, Ideas and Innovations in Technology**, v. 4, n. 3, p. 810–813, 2018. ISSN 2454-132X. Paper ID V4I3-1437. Disponível em: <https://d1wqtxts1xzle7.cloudfront.net/57587668/V4I3-1437-libre.pdf>.

Hankammer, S. S. *et al.* From phonebloks to google project ara: a case study of the application of sustainable mass customization. **Procedia CIRP**, v. 51, p. 72–78, 2016.

Lopes, M. E. F. **Smartphones and the influence of advertising on consumer behavior**. 2022. Dissertação (Mestrado) — Universidade de Fortaleza, Fortaleza, 2022.

Magera, M. **The paths of waste: from planned obsolescence to reverse logistics**. Campinas: Átomo, 2013.

Mendes, A. F. B. S. F. **The responsibility of Product Design in creating the new through the used**. 2022. Tese (Doutorado) — University of Porto, Porto, 2022.

Oliveira, A. M. d.; Santos, G. Leal dos. **Comportamento do consumidor: um panorama brasileiro dos impactos da pandemia da COVID-19 na jornada de compra**. Rio de Janeiro, RJ, Brasil, 2022. Acesso em: 10 jan. 2026. Disponível em: <http://www.repositorio.poli.ufrj.br/monografias/projpoli10038224.pdf>.

Padilha, V.; Bonifácio, R. C. A. Desiring, buying and discarding: from advertising persuasion to planned obsolescence. **Ciência & Cultura**, v. 68, n. 4, p. 47–55, 2016.

Pazmino, A. V. A reflection on social design, eco design and sustainable design. In: **Brazilian Symposium on Sustainable Design**. [S.l.: s.n.], 2007. p. 1–4.

Ribeiro, P. H. L.; Rezende, E. C.; Franco, J. R. Product obsolescence: design and market dynamics. **DAT Journal**, v. 6, n. 4, p. 208–222, 2021.

Santos, R. H. M.; Guarnieri, P.; Streit, J. A. C. Planned and perceived obsolescence: a survey on the perception of the life cycle with users of cell phones. **Gestão & Planejamento**, v. 22, 2021.

World Health Organization. **Electronic waste (e-waste)**. 2024. Fact sheet. Disponível em: <https://www.who.int/news-room/fact-sheets/detail/electronic-waste-(e-waste)>.