Journal of
Manufacturing and Materials Processing

MDPI

Article

Business Models Definition for Next-Generation Vision Inspection Systems †

Francesco Lupi [1,*], Antonio Maffei [2] and Michele Lanzetta [3]

[1] Department of Information Engineering, University of Pisa, 56122 Pisa, Italy
[2] Department of Production Engineering, KTH Royal Institute of Technology, 114 28 Stockholm, Sweden; maffei@kth.se
[3] Department of Civil and Industrial Engineering, University of Pisa, 56122 Pisa, Italy; lanzetta@unipi.it
* Correspondence: francesco.lupi@phd.unipi.it

† This is an extended version of our paper published in Lupi F, Maffei A, Lanzetta M. CAD-based autonomous vision inspection systems. *Procedia Comput. Sci.* **2024**, *232*, 2127–2136. In Proceedings of the 5th International Conference on Industry 4.0 and Smart Manufacturing (ISM 2023), Lisboa, Portugal, 22–24 November 2023.

Abstract: Automated industrial Visual Inspection Systems (VIS) are predominantly designed for specific use cases, resulting in constrained adaptability, high setup requirements, substantial capital investments, and significant knowledge barriers. This paper explores the business potential of recent alternative architectures proposed in the literature for the visual inspection of individual products or complex assemblies within highly variable production environments, utilizing next-generation VIS. These advanced VIS exhibit significant technical (hardware and software) enhancements, such as increased flexibility, reconfigurability, Computer Aided Design (CAD)-based integration, self-X capabilities, and autonomy, as well as economic improvements, including cost-effectiveness, non-invasiveness, and plug-and-produce capabilities. The new trends in VIS have the potential to revolutionize business models by enabling as-a-service approaches and facilitating a paradigm shift towards more sustainable manufacturing and human-centric practices. We extend the discussion to examine how these technological innovations, which reduce the need for extensive coding skills and lengthy reconfiguration activities for operators, can be implemented as a shared resource within a circular lifecycle. This analysis includes detailing the underlying business model that supports shared utilization among different stakeholders, promoting a circular economy in manufacturing by leveraging the capabilities of next-generation VIS. Such an approach not only enhances the sustainability of manufacturing processes but also democratizes access to state-of-the-art inspection technologies, thereby expanding the possibilities for autonomous manufacturing ecosystems.

Keywords: visual inspection; flexibility; reconfigurability; autonomy; manufacturing; business model; computer-aided design; servitization; sustainability; circular economy

Citation: Lupi, F.; Maffei, A.; Lanzetta, M. Business Models Definition for Next-Generation Vision Inspection Systems. *J. Manuf. Mater. Process.* **2024**, *8*, 161. https://doi.org/10.3390/jmmp8040161

Academic Editors: Mark J. Jackson and Antonio Padovano

Received: 28 April 2024
Revised: 15 July 2024
Accepted: 23 July 2024
Published: 27 July 2024

1. Introduction

Flexibility and reconfigurability in manufacturing are crucial for the enablement of agile and resilient production systems using adaptable and reconfigurable machines capable of handling diverse product variants or disruptive production changes [1,2]. Despite the significant evolution in the manufacturing domain towards these properties, Vision Inspection Systems (VIS), introduced more than half a century ago, are still mostly related to dedicated solutions [3]. In this context, the latest frontiers of research have seen a significant boost in recent years, aiming to realign VIS with the current evolution of manufacturing by introducing the next generation of these systems [4]. As shown in Figure 1, these systems are characterized by four main properties (i.e., digital nature, flexibility, reconfigurability and autonomy). Considering the temporal dimension, and according to Lupi et al. 2024 [4], autonomy stands for the latest development attempts in the manufacturing domain, incorporating specific aspects enabled by features inherited from the other properties, as indicated by the dotted arrows in Figure 1. From a technical standpoint, the evolution toward next-generation VIS is rooted in two parallel upgrades in their foundation elements:

- **Hardware**: the development of flexible (i.e., computer-controllable) physical architectures integrating general purpose Numerically Controlled (NC) axes, six-Degree-of-Freedom (6DoF) industrial robots/cobots, drones or Automated Guided Vehicles (AGV) capable of positioning and orienting cameras and lighting systems with nearly unlimited flexibility within the working volume and according to constructive constraints. The physical components of these systems are designed to include reconfigurability features such as modularity (i.e., modular components), integrability (i.e., modules designed with interfaces for integration), convertibility and scalability (i.e., fast ramp-up), and customized flexibility (around a specific parts family).
- **Software**: To achieve the previously described aims of reconfigurability and flexibility, software components need to exhibit the same aspects of modularity, integration, and easy setup and reconfiguration via user-friendly forms of Graphical User Interface (GUI) or Human Machine Interface (HMI), reducing the need for high-skilled personnel in low-coding tasks and complex automation integration. In this context, the potential of fully exploiting Computer Aided Design (CAD) three-dimensional (3D) models as a single point of truth (e.g., adopting a universal CAD file such as Standard for the Exchange of Product Data (STEP) and using Product Manufacturing Information (PMI)) has been recently included in these VIS new frameworks. These approaches each present a different Level of Automation (LoA) according to their degree of human interaction.

Beyond addressing the technical challenges extensively discussed in [4–6], this wave of next-generation VIS has the potential to foster new business models rooted in sharing economies [7] or the X-as-a-service concepts [8,9], shifting from Engineer To Order (ETO) [10] to Configure To Order (CTO) models [11,12]. This paper is an extended version of the award-winning Best Student Paper at the International Conference on Industry 4.0 and Smart Manufacturing (ISM2023) [5], and its latest evolution, recently published in [4], exploring the avenues of new related Business Models (BMs).

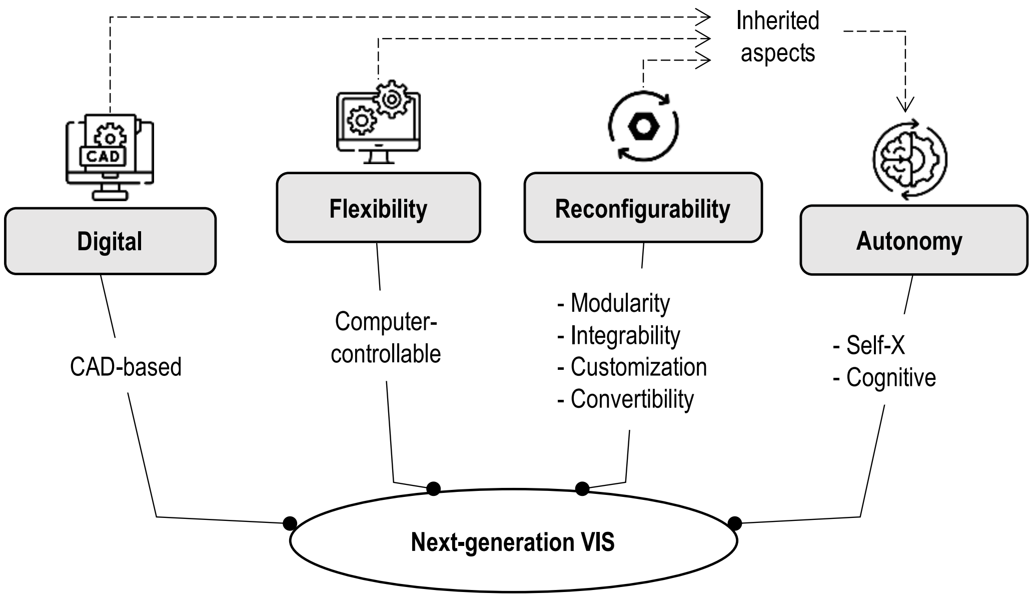

Figure 1. The main properties and related aspects of next-generation VIS. The dotted arrows highlight how autonomy is enabled by certain aspects inherited from the other properties.

From an innovation theory perspective, while technological advancement marks progress, true innovation occurs when applied effectively in real-world scenarios. This application process is critical, as it translates theoretical or experimental technologies into practical solutions that meet specific market needs or consumer demands [13]. However, transitioning from a mere technology to a successful innovation does not culminate with its application alone; it requires the careful formulation of a BM capable of generating revenues [14]. In this sense, the BM has a pivotal role in capturing economic value from emerging technologies. These technologies, originating from research activities, present an intrinsic potential value proposition that can only be actualized through a meticulously designed process of value creation and capture. The BM acts as a heuristic framework bridging the gap between the technical potential and the realization of economic value [15].

The definitions of a BM are multiple and often unclear [16]. In this work, the BM articulates the value proposition, clarifying the benefits the new technology provides to users. It then identifies the target market segment, pinpointing the users for whom the technology is intended and the purposes it serves, along with specifying the mechanisms for revenue generation. Furthermore, it defines the structure of the value chain within the firm which would be necessary for producing and distributing the offering, and determines the complementary assets required to support the firm's position in this chain. Additionally, the model estimates the cost structure and profit potential based on the chosen value proposition and value-chain configuration. It also describes the firm's strategic position within the value network that links suppliers and customers, identifying potential partners and competitors. Finally, it formulates the competitive strategy, outlining how the innovating firm will achieve and sustain a competitive advantage over rivals.

As to the main gaps in the literature, the actual implementation of such a next-generation VIS is missing, along with an associated business-oriented perspective. This work will investigate how these recent technological solutions could be embedded into a BM for successful market application: defining and discussing the value proposition in relation to stakeholders and connecting it with established value creation and capture mechanisms that underscore how these frameworks supports sustainable BM archetypes in the domain of sharing and circular economies.

The Research Question (RQ) addressed in this work is: *How to comprehensively analyze and define the BM of next-generation VIS throughout its entire lifecycle?*

2. Background

Breaking the boundaries of conventional VIS, innovative solutions based on flexible, reconfigurable, autonomous and CAD-based systems have been adopted as central aspects of the new BM proposal. Section 2.1 provides a concise overview of the literature and related works on next-generation VIS; Section 2.2 delves into the requirements, characteristics, and trends of BMs; and Section 2.3 provides background on the introduction of a specific BM for next-generation VIS.

2.1. Next-Generation VIS

Next-generation VIS are designed to be cost-effective solutions which can be seamlessly integrated into production lines as plug-and-produce devices, requiring minimal modifications to existing processes and presenting a quick and user-friendly configuration.

Figure 2 illustrates a recent framework in the field which introduced the definition of the Reconfiguration (ReCo) file to streamline the reconfiguration of flexible and reconfigurable VIS fully and automatically via software. The ReCo file was presented as a means of allowing seamless storage, exchange, and integration of inspection tasks within different plants. As noted by the authors, mechanical parts with varying functions, such as splines or threads, might have similar appearances and share the same inspection algorithm. Consequently, an application was proposed to select an existing ReCo file from a database with similar vision inspection features, following a variant approach.

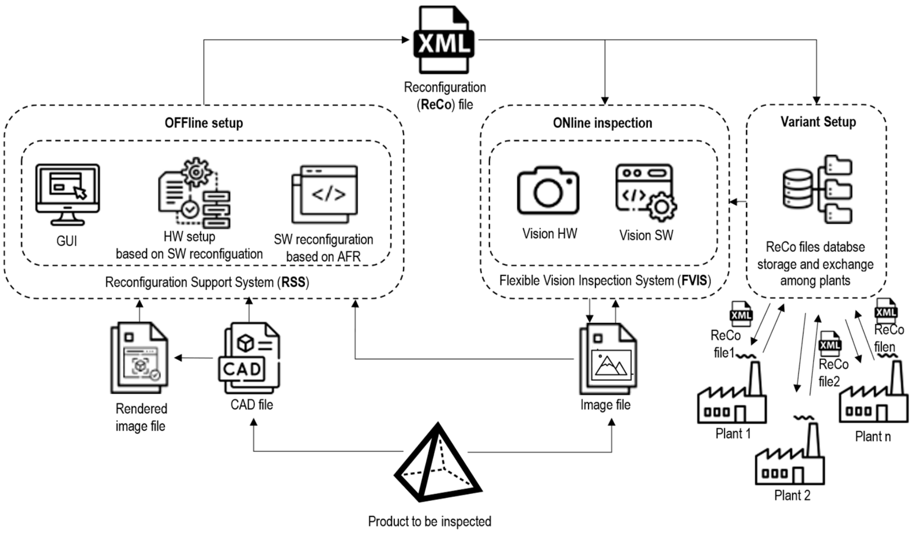

Figure 2. The schematical representation of the pioneering framework proposing the utilization of CAD information for reconfiguring the ReCo file via user-friendly reconfiguration support system (RSS). Image reprinted from Lupi et al., 2023 [6] under CC BY 4.0 license.

Following the idea of the ReCo file initiated in [6], Figure 3 outlines the framework's evolution, incorporating the ReCo file as primary output. The main contribution lies in defining five interconnected modules essential for enhancing the automation of ReCo file generation. In this context, higher LoA (defined as autonomous) was the goal of the work, including the self-planning of the robotic path to inspect the product.

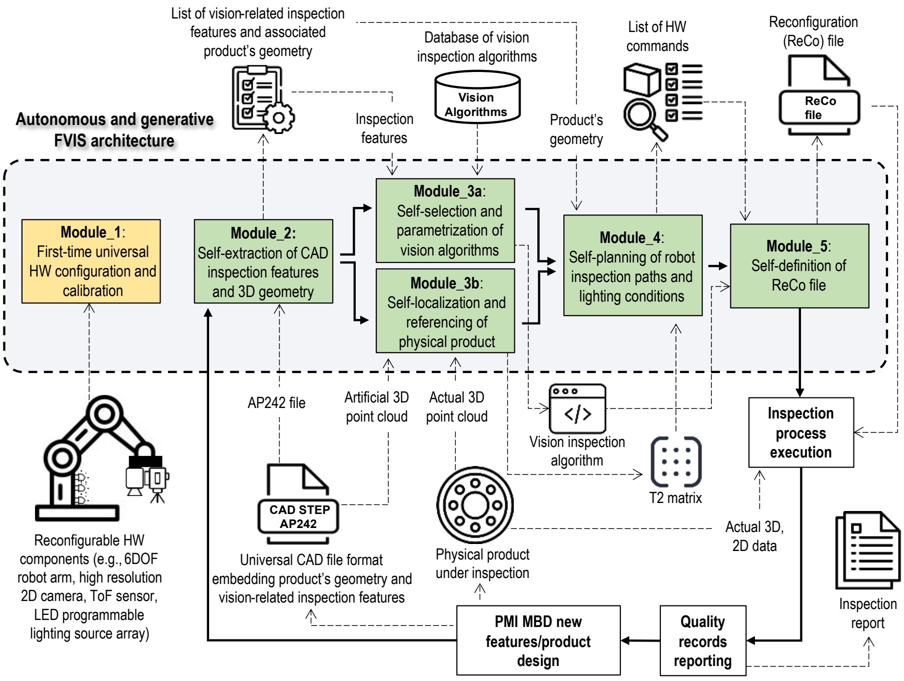

Figure 3. The framework for Autonomous-VIS, highlighted within the light gray dotted box. Input/output is shown by light-dotted arrows, while squared boxes represent activities. Module_1 (yellow box) refers to the initial hardware configuration and calibration, which is performed outside of the inspection loop. Modules_2-5 (green boxes) are part of the inspection loop and are connected to other activities outside the scope of the current study (depicted within boxes). Image reprinted from Lupi et al., 2024 [5] under CC BY 4.0 license.

Further advancements were made in the latest version of the framework (Figure 4), which includes the formal definition of the ReCo and Config files, increasingly refining the logical patterns behind the model with better identification of the initial configuration activity, and a fully autonomous pipeline from CAD to the ReCo file, as well as the recognition of three main sources of information for 3D CAD semantic annotation [4]. As shown in Figure 4, the updated framework allows the fully autonomous generation of the ReCo file, starting from the initial annotated 3D CAD file with specific inspection PMI during the design stage. In this phase, the operator attaches geometrical or textual semantic annotations to specific geometric entities, generating an enriched 3D CAD file.

This information is then automatically extracted and used to select the best inspection algorithm from a given library. The product, randomly placed in the system's working area, is scanned, and the obtained point cloud is registered with the synthetic one sampled from the 3D CAD model. The final module self-defines the inspection routines in order to avoid obstacles and inspects all of the surfaces on the list. This information is stored in the ReCo file, which is subsequently used for motion and vision execution. Orchestration between the various modules is performed via dedicated Application Programming Interfaces (APIs) to implement a modular software architecture. In this final version of the framework, the inclusion of industrial marketplace hubs for vision inspection libraries has been proposed, opening avenues for entirely new business models rooted on digitalization and "servitization" [4].

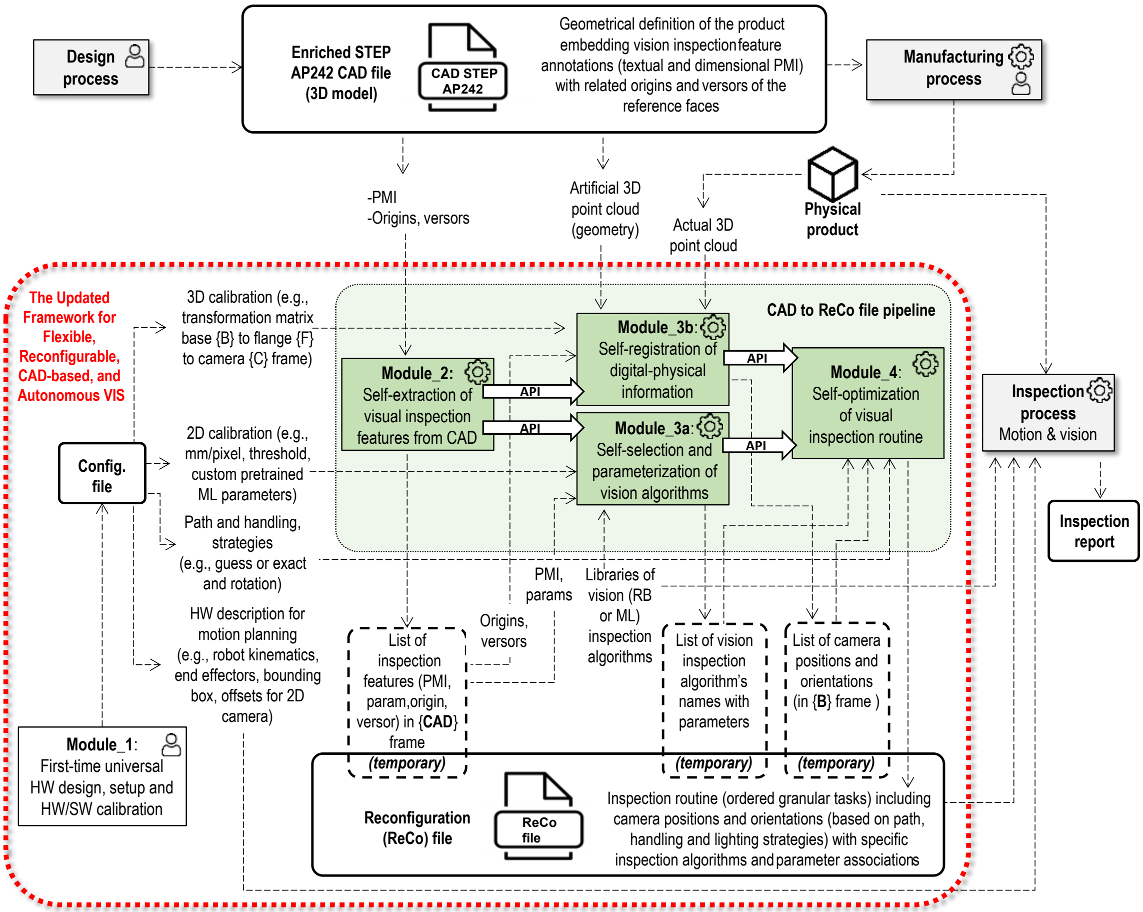

Figure 4. The final version of the next-generation VIS framework, as reprinted from Lupi et al., 2024 [4] under CC BY 4.0 license. The red-dotted area denotes the evolution of the framework previously described in Figure 3. The green area is the CAD-to-ReCo file pipeline.

2.2. Requirements, Peculiarities, and Trends of BMs

The significance of BMs in capturing value from technological innovations is notably highlighted by the understanding that merely possessing advanced technology does not inherently lead to value creation. Instead, firms must design and implement BMs that effectively exploit this technology by aligning it with market and regulatory environments. These models play a crucial role in determining how firms capture economic value through mechanisms such as Intellectual Property (IP) protections, unique technology features, and scalability potential [3]. In this sense, the correct definition of the value proposition behind any potentially innovative element is the fundamental generative step of any successful BM [17]. This involves the strategic configuration of internal and external resources to maximize the potential of the technology. It also necessitates making continuous adjustments in operational strategies to respond to ongoing technological advancements and market feedback.

Furthermore, the adaptability of BMs in response to rapidly changing conditions is underscored by the need for firms to possess dynamic capabilities. These capabilities enable firms to sense new opportunities, seize them efficiently, and transform operations and strategies where necessary. This adaptability is particularly crucial in markets driven by technology, where the pace of change is quick and technology lifecycles are increasingly brief [18].

The strategic importance of understanding the ecosystem in which a business operates, including regulatory frameworks, competitive threats, and the role of complementary assets and services, is also relevant [19]. A successful BM not only addresses how to bring a product or service to market but also how it interacts with the broader economic and social infrastructure. This comprehensive perspective on the integration of BMs with technological innovation suggests that the robustness of a BM depends significantly on its capacity to continually adapt and reorient strategies to maintain a competitive edge, highlighting a critical aspect of strategic management in contemporary markets [14].

Further expanding on this concept, scholars provide frameworks that illustrate how BMs can be designed by starting from different sets of standard elements. Any business venture, especially those based on new technology, starts with a clear comprehension of the value that potential customers gain from using the innovation. Value in this context is not purely derived from the physical attributes of a product but is an economic metric that must be viewed from various stakeholder perspectives. This is especially true for complex products like VIS that integrate hardware, software, and services, presenting a multifaceted value proposition. In this context a value proposition can be understood as a set of elementary offerings, each capturing a specific fraction of the overall value [20].

These offerings collectively make up the total value proposition and are delivered through distinct stages during the process of bringing the focal invention to the market (cf. Table 1).

Table 1. The phases in the lifecycle of a value proposition [20].

Phase Type	Phase Description
Creation	Involves designing and customizing the product to enhance its value.
Purchase	Focuses on the transaction phase, in which ease of purchase, fast delivery, and reliability are key value enhancers.
Use	The traditional phase in which the product is utilized; the value is maximized when it meets current customer needs.
Renewal	Entails updating or upgrading the product to prolong its use, which is more valuable when it fits the customer's increasing requirements, occurs non-invasively, and restores the product to a like-new condition.
Transfer	Deals with the end of the product's lifecycle, focusing on the disposal or repurposing of the product to maximize end-of-life value and ease of disposal.

Formalizing these offerings in conjunction with each potentially innovative element of the examined technological advancement facilitates a more precise alignment between the creation and capturing of value, as well as the BMs designed to exploit these elements [11]. A new BM may focus on a single offering, a specific set of offerings, or even a fraction of an offering.

The successful application of the focal technology investigated requires the definition of a complete set of BMs and related stakeholder interests that can comprehensively address the defined value offerings within their operational frameworks [20]. In detail,

- **Value-generating activities** refer to the core actions or processes that a business undertakes to produce goods or services that are valuable to customers. These activities are crucial, as they directly contribute to the primary value proposition of a business, enhancing customer satisfaction, driving sales, and improving market positioning. Examples include product design, production, marketing, and customer service. Each of these activities adds value to the firm's offerings and helps to attract and retain customers by meeting their needs and expectations effectively.
- **Value-capturing mechanisms**, on the other hand, are the strategies or methods a company uses to retain some portion of the value its activities create. This is essential for generating revenue and ensuring the company's long-term viability and profitability. Value capturing can occur through various means, such as pricing strategies, cost control, intellectual property management, and innovative revenue models. For instance, a company might implement a premium pricing strategy to capture more value from high-quality products or adopt a subscription model to ensure steady revenue flow over time.

Sustainable BM archetypes represent a structured way to categorize the various strategies businesses can employ to integrate sustainability into their core operations [21]. Among them, the most relevant for this study include the following:

1. **Maximize material and energy efficiency**: This archetype focuses on optimizing the use of resources to reduce waste and increase efficiency. Businesses adopt practices that streamline operations and minimize energy consumption, such as implementing more efficient production technologies or redesigning products to use less material [22].
2. **Create value from waste**: Turning waste into a resource is a key strategy in this archetype. Companies develop processes to reuse, refurbish, and recycle materials that would otherwise be discarded. This can involve innovative ways to repurpose by-products or the production of waste materials valuable to other industries [23].
3. **Substitute with renewables and natural processes:** Here, the focus is on replacing non-renewable resources with renewable ones, such as using bio-based materials or incorporating the use of wind, solar, and other sustainable energy sources into operations. This also includes adopting natural processes that are less resource-intensive and more benign with respect to the environment [24].
4. **Deliver functionality rather than ownership**: This model shifts the focus from selling products to providing services that fulfill customer needs. For instance, instead of selling cars, a company might offer a car-sharing service. This helps reduce material use and can lead to innovations in how products are designed and used [25,26].
5. **Adopt a stewardship role**: Companies adopting this archetype take responsibility for the impacts their operations have on the environment and society. They engage in practices that protect natural resources, support community development, and ensure that their operations are sustainable in the long term [27].
6. **Encourage sufficiency**: Reducing consumption is at the heart of this archetype. Companies employing this strategy focus on promoting products that are more durable and able to be repaired, as well as encouraging consumers to buy less, but also to purchase products of a higher quality. This could also involve promoting sharing platforms or redesigning products for longer lifecycles [28].

7. **Develop scale-up solutions:** The focus here is on expanding the reach of sustainable practices in order to have a broader impact. This might involve scaling-up successful pilot projects, franchising, or forming alliances to spread sustainable innovations more widely.

2.3. BM for Next-Generation VIS

Current VIS are often characterized by their high costs and specialized nature, which generally restrict their application to specific production processes. These systems are typically designed with a rigid architecture, both technically and financially, meaning that they are optimized for a particular type of product or manufacturing environment and are difficult to adapt to different settings. Financially, the investment required to implement these systems is substantial, with the costs often justifiable only within high-volume or high-value production scenarios [29].

Moreover, traditional VIS have a linear lifecycle. Once deployed, they are used for their intended purpose until they become technologically obsolete, or the production requirements change significantly. At best, components of these systems can be reused or repurposed, but this often involves considerable costs related to disassembly, reconfiguration, and integration into new production lines. This lack of flexibility not only limits the system's long-term value but also contributes to increased waste and resource consumption, as adapting to new requirements can be as resource-intensive as procuring new systems. This scenario underscores the need for more adaptable and financially flexible inspection systems in the manufacturing industry [30].

Autonomous production systems like the targeted next-generation VIS are designed to swiftly deploy and handle a diverse array of tasks, showcasing remarkable manufacturing agility and resilience [9]. These features, concerning both reconfigurability and flexibility, are crucial in adapting to the rapid and often disruptive changes, as well as varying turbulent demands within modern production environments facing variant/generative production domains [6,9,31].

Simultaneously, these systems contribute significantly to sustainability. By allowing for the sharing of production resources, the proposed next-generation VIS transform what would traditionally be a single lifecycle investment into a circular asset. This not only maximizes the utility of the resources but also supports a sustainable model in which assets have multiple lifecycles, reducing waste and promoting resource efficiency. Through this innovative approach, these systems reshape the economic and environmental paradigms of industrial inspection, fostering a more sustainable and adaptable manufacturing landscape grounded in adaptable rather than customized, rigid, and monolithic solutions.

The value-based view of next-generation VIS BMs centers on the premise that businesses can create significant value through the innovative design and management of their transactions and interactions with all stakeholders. Key aspects of this approach include novelty, lock-in, complementarities, and efficiency, each of which can be leveraged across various business contexts [32].

The study aims to accomplish the following key objectives:

1. **Define the value proposition along the whole lifecycle**: This objective seeks to articulate the value proposition of the next-generation VIS by identifying and detailing specific value offerings at each stage of the system's lifecycle. This also includes the identification of target stakeholders for each value offering. The goal is to establish a clear and continuous narrative of value creation, emphasizing how each phase contributes to the overarching benefits derived from the next-generation VIS.
2. **Discuss the value-generating activities and value-capturing mechanisms for each value offering**: For each identified value offering, the paper will explore the associated value-generating activities—those actions or processes that directly enhance the utility, efficiency, or desirability of the next-generation VIS. Simultaneously, the study will examine the value-capturing mechanisms employed to secure economic benefits,

ensuring the financial sustainability of the system throughout its lifecycle. This dual analysis will provide insights into how value is both created and retained.

3. **Determine the manner in which the resulting BM maps onto the sustainable BM archetypes**: Finally, the research will investigate how the focal concept aligns the identified business models with respect to the sustainable BM archetypes presented above.

Through the pursuit of the objectives related to the RQ, the research aims to understand the economic and sustainable impacts of the next-generation VIS, thereby offering valuable insights for manufacturers, integrators, and end users seeking to leverage advanced inspection technologies in their operations. The findings are expected to contribute significantly to the body of literature on servitization and sustainable business practices within the domains of Industry 4.0/5.0 and advanced manufacturing technologies.

3. Methodology

The BMs for next-generation VIS will be analyzed and synthesized following the method used in [11] and presented in Figure 5, below. This methodology is structured to provide a comprehensive understanding of the value proposition associated with next-generation VIS by examining it along two primary dimensions: spatial and temporal.

The proof of concept for the next-generation VIS will be examined across two dimensions to fully describe the system's value proposition, namely, the spatial and the temporal dimensions. The spatial dimension includes all the requirements underpinning the innovative elements that contribute to the embodiment of the next-generation VIS concept. It involves identifying the hardware and software components, integration techniques, and technological advancements that constitute the VIS. Key factors such as flexibility, reconfigurability, CAD-based integration, self-X capabilities, and autonomy will be analyzed. The temporal dimension considers the entire lifecycle of the next-generation VIS, from creation and purchase to use, renewal, and transfer. Each phase of the lifecycle will be analyzed to understand how the VIS delivers value over time. This analysis will highlight the value proposition at each stage, ensuring a comprehensive view of how the system meets the needs of its users throughout its operational life.

The analysis will highlight the entire value proposition of the next-generation VIS and articulate it as a set of basic value offerings. Each value offering will be detailed in terms of its contribution to the overall system and its significance at various phases of the lifecycle. This step ensures that each element of the VIS is understood in the context of its value to the end user. Subsequently, the identified value offerings will be allocated to a set of stakeholders who can potentially fulfill them. This involves mapping out the roles and responsibilities of different stakeholders, such as Original Equipment Manufacturers (OEMs), System Integrators, End Users, and Vision Inspection System as a Service (VISaaS) Providers. Each stakeholder's involvement will be analyzed to understand how they contribute to and benefit from the next-generation VIS.

Finally, the inferred value-generating activities and value-capturing mechanisms will be presented and discussed in relation to their alignment with various sustainable BM archetypes. This involves identifying the core activities that generate value for each stakeholder and understanding the mechanisms through which value is captured, such as pricing strategies, cost efficiencies, and competitive advantages. The analysis will align these activities and mechanisms with sustainable business model archetypes, such as maximizing material and energy efficiency, creating value from waste, substituting with renewables, delivering functionality rather than ownership, adopting a stewardship role, encouraging sufficiency, and developing scale-up solutions. By following this structured methodology, the study aims to provide a robust framework for understanding and implementing effective business models for next-generation VIS, ensuring their technological advancements are matched with viable and sustainable economic strategies.

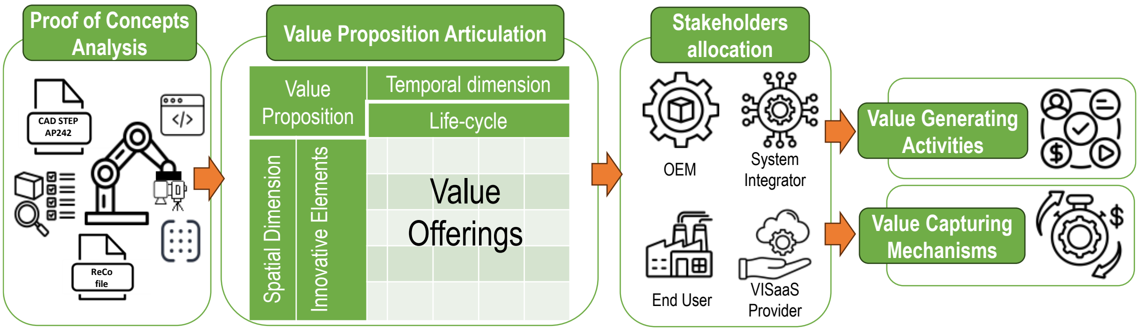

Figure 5. Graphical summary of the methodology used in this work to analyze and synthesize the BMs for the next-generation VIS.

4. Business Model of Next-Generation VIS

The first step in defining the BM is identifying the value offerings and allocating them among different stakeholders. In line with the method proposed in [11], this process involves analysis of the value proposition in two dimensions: (1) the spatial dimension, including all the innovative elements and features of the proposed technological innovation; (2) the temporal dimension, featuring the five well-established phases of Creation, Purchase, Use, Renewal and Transfer (see Table 1 for a detailed description).

In order to define (1), it is important to remark upon the experimental nature of the proposed systems, which, at this stage, are aimed at delivering proof-of-concepts rather than fully commercial embodiments. In view of this, in order to enable the analysis of the BM and consequent characterization of the application of the next-generation VIS concepts, it is thus necessary to extract the requirement from the described functionalities of the target solutions rather than one based on a well-grounded technical description. The following table, Table 2, presents the relevant requirement for the BM synthesis.

Table 2. Requirement for the synthesis of a BM for the proposed next-generation VIS.

Category	Requirement
Hardware	Built using commercial 6DoF industrial robots/cobots, NC rotative/linear axes, drones, AGVs as well as cameras, lights, and others. Few customized components. Integrated within a compact and transportable solution.
Software	Commercial and integrated within an autonomous pipeline supporting the whole process. Customized modules for intra-communication between different platforms and for handling the self-X algorithms. Customary interface for the end user.
Process	Utilization of semantically enriched CAD data as a single point of truth. Autonomous self-X behavior: extraction of features, selection and parametrization of algorithms, product registration (including sensors calibration), and planning and execution of the inspection. Input: enriched CAD file with the geometry of the component and semantic annotations regarding the desired performed task (key information for each inspection feature: point, versor, and text/dimensions). Config file for hardware and software setup. Output: ReCo file.

Leveraging this requirement, it is now possible to detail the temporal dimension (2) of the next-generation VIS value proposition. For each phase it is possible to identify the main stakeholders that can benefit from that specific value offering. Table 3, following the table below, summarizes the related findings.

Table 3. Lifecycle of the value proposition of next-generation VIS and related main stakeholders. ⬛ = Original Equipment Manufacturer (OEM), 🟧 = System integrator, ⬜ = End user, 🟦 = Vision Inspection System as a Service (VISaaS) provider.

Lifecycle Phase	Requirement	Stakeholders
Creation	The compact and transferable next-generation VIS are built, integrating different commercial and customized hardware components and developing the necessary hardware for interfacing with the customer and handling the self-X behaviors by integrating different commercial software with ad hoc intra-communication functionalities, delivering an autonomous pipeline from the annotated CAD input to the final ReCo file.	⬛ 🟧
Purchase	This phase includes the transaction within which the next-generation VIS unit reaches the final user.	🟦
Use	This is the phase in which the system is deployed and used to perform the task for the current end-user.	⬜
Renewal	This phase includes necessary upgrades and maintenance of the next-generation VIS system.	⬛ 🟧
Transfer	This phase is here similar to the "Purchase" phase, as it involves the transfer of the next-generation VIS to the subsequent end-user.	🟦

As industries increasingly move towards service-oriented models—a shift referred to as "servitization"—the need for robust frameworks that encapsulate both the creation, and the capture of value becomes more pronounced.

Servitization, particularly in the context of manufacturing, involves transforming traditional product-centric offerings into comprehensive service-oriented solutions. This transition is driven by the desire to provide added value to customers through services that extend beyond mere product delivery, encompassing maintenance, updates, and ongoing support. In such models, the product itself becomes a platform for delivering these extended services, changing the revenue streams from one-time product sales to recurring service-fees and subscriptions.

The proposed lifecycle of the value proposition for the next-generation VIS embodies this shift towards servitization. It has been designed to ensure that each stakeholder involved in the ecosystem—ranging from OEMs and system integrators to end users and VISaaS providers—engages in activities that not only generate value but also capture it effectively, ensuring a sustainable BM.

In the following, Table 4 summarizes the main findings in terms of value-generating activities and value-capturing mechanisms for each stakeholder, as implied by the proposed embodiment of the technical solutions presented in this work.

Table 4. Summary of the value-generating activities and value-capturing mechanisms for each stakeholder.

Stakeholder	Value-Generating Activities	Value-Capturing Mechanisms
OEM	Producing and selling high-quality, reliable equipment that forms an integral part of the next-generation VIS.	Selling ownership.
System integrator	Integrating hardware (HW) and software (SW) to build tailored next-generation VIS solutions for generic industrial applications.	Charging for integration services, ongoing technical support, follow-up and system optimization to ensure seamless operation.
End user	Using the next-generation VIS to perform precise and efficient inspections of products to ensure quality compliance and reduce waste.	Cost savings and enhanced productivity: realizing increased operational efficiency and lower defect rates, which translate to higher product quality and reduced costs.
VISaaS provider	Renting or leasing the next-generation VIS to different end users, allowing for flexible, usage-based access over multiple lifecycles. Offering vision algorithms or ReCo file development as services.	Subscription-based and usage-based pricing: generating recurring revenue through subscription models or pay-per-use agreements which provide continuous income while offering scalability to customers.

In summary, the relevant archetypal stakeholders and related processes and commercial relationships can be described as follows:

1. **OEMs**: OEMs are pivotal in the lifecycle of next-generation VIS. These stakeholders are responsible for the creation and renewal of value by supplying the essential hardware components and the engineering expertise required to construct and continuously improve the system. OEMs benefit from both the initial sale of equipment and the ongoing revenue generated through maintenance, upgrades, and the provision of replacement parts necessary to keep the systems operational and up-to-date with respect to technological advancements.
2. **System integrators**: System integrators play a critical role in aligning the various technological components from different manufacturers into a cohesive, functioning system. They specialize in integrating hardware and software to create a tailored solution that meets specific operational needs of the end users. Like OEMs, system integrators also benefit from the creation and ongoing renewal of value, particularly through engineering services, system upgrades, follow-up, and maintenance. Their expertise ensures that the next-generation VIS operate efficiently within the existing manufacturing infrastructure.
3. **VISaaS Providers**: VISaaS providers are a newly defined category of stakeholders in the next-generation VIS ecosystem. They own the inspection systems and offer them to manufacturing companies under a pay-per-use scheme. This model allows end users to leverage advanced inspection technologies without the upfront capital investment typically associated with purchasing and installing such systems. VISaaS providers manage the deployment, maintenance, and upgrading of the systems, ensuring they deliver consistent performance and technological relevancy. This category of stakeholders may also include those software developers in the industrial marketplace hub who propose developing VIS algorithms for vision inspection library creation, as well as services for custom ReCo file development.

4. **End users**: End users are the manufacturers who employ the next-generation VIS to enhance the quality and efficiency of their production processes. They benefit from the advanced capabilities of the VIS, such as increased accuracy, faster processing times, and reduced manual labor and low-coding skills, without having to invest in and manage the complex technology directly. By utilizing VISaaS, they can adapt to varying production demands and technological changes more flexibly and cost-effectively.

The stakeholders identified in the context of the next-generation VIS are presented as general forms to delineate their typical roles and contributions. However, in practice, the boundaries between these roles can be fluid, with a single firm potentially assuming multiple functions. For instance, an OEM could not only manufacture components but also integrate these components into complete systems. Furthermore, the same OEM might offer the integrated system directly to end users through a VISaaS model, effectively blending the roles of manufacturer, integrator, and service provider.

The next-generation VIS described in the study align well with various sustainable BM archetypes, facilitating a significant shift towards more sustainable manufacturing practices. In more detail, these systems accomplish the following:

1. **Deliver functionality rather than ownership**: The next-generation VIS support a service-oriented BM, particularly through the VISaaS model. This approach reduces the need for individual companies to own and maintain specialized inspection equipment, instead providing access to high-quality inspection capabilities as a service, which reduces overall material consumption and focuses on functionality.
2. **Develop scale-up solutions**: The technology behind the next-generation VIS can be easily scaled and adapted to various industrial contexts, allowing for broad implementation across different sectors and geographies. This scalability enables widespread adoption of advanced inspection techniques, spreading the benefits of sustainable manufacturing practices more widely and contributing to global sustainability goals.

In addition to these direct impacts, the next-generation VIS open the market of more reliable quality control for SMEs and thus contribute indirectly also to other archetypes, as follows:

3. **Maximize material and energy efficiency**: The next-generation VIS enhance efficiency in manufacturing processes by optimizing inspection routines and reducing the need for repeated processes through its inspections. This leads to less material waste and lower energy consumption, as defects are identified more accurately and earlier in the manufacturing process, minimizing rework and scrap.
4. **Create value from waste**: While the primary function of the next-generation VIS is not directly related to waste management, quality control can help identify parts that can be reworked instead of discarded, indirectly contributing to waste reduction. Moreover, by ensuring higher quality control, materials that would otherwise be discarded due to defects can be saved and utilized effectively.
5. **Encourage sufficiency**: The next-generation VIS contribute to this archetype by ensuring the system extends its lifespan through reconfigurability and by reducing the need for component customization or recommissioning, thanks to their high flexibility and modularity.

5. Summary and Conclusions

Novel frameworks such as next-generation VIS pave the way for disruptive changes in the market of VIS, introducing concepts such as configure-to-order and servitization, with the aim of transitioning towards VISaaS. Unlike conventional systems, which are rigid, both technically and financially, the next-generation VIS are designed with adaptability and resilience in mind, allowing them to be easily integrated into different production environments without the high costs associated with reconfiguration. Within this context, the focus of the current paper has been on the basic requirements necessary for formulating a business model for the next-generation VIS, stressing the importance of VISaaS providers, among various mapped stakeholders. As its main contributions, this work opens the door for specific business strategies leveraging the achieved advancements both in hardware (e.g., general purpose elements such as robot/cobots, drones, AGV, NC axes as well as sensors and lighting systems) and software (i.e., ReCo file, Config file, and marketplace) components of next-generation VIS.

One of the groundbreaking features of the next-generation VIS is their capability to transform VIS into a shareable resource. This innovation not only enhances the accessibility and democracy of advanced inspection technologies but also promotes a circular-economy approach within the manufacturing sector. By enabling the sharing of the system among different users and applications, the next-generation VIS extend their lifecycles significantly. Each unit can be redeployed multiple times across various production scenarios, maximizing its utility and reducing the need for new resources with each new application, fostering circularity.

Among the merits of this work, a systematic mapping of the main stakeholders involved in VIS domain, including OEMs, system integrators, end users, and VISaaS providers, is reported. Future research may extend the analysis to encompass a broader array of stakeholders, such as technology developers, equipment suppliers, software providers, regulatory bodies, maintenance and support services, academic and research institutions, investors and financial institutions, supply chain partners, customers, and consumers, and discuss how the proposed industrial vision marketplace hub could be designed to enable the integration of these entities, allowing the BM to grow into an ad-hoc ecosystem, enhancing strategic decisions and operational efficiencies.

Author Contributions: Conceptualization, F.L., A.M. and M.L.; methodology, F.L. and A.M.; software, F.L.; validation, F.L., A.M. and M.L.; formal analysis, M.L.; investigation, F.L.; resources, M.L.; data curation, F.L.; writing—original draft preparation, F.L.; writing—review and editing, F.L., A.M. and M.L.; visualization, F.L.; supervision, M.L.; project administration, M.L.; funding acquisition, M.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding. This paper is the extended version of the paper awarded the Best Student Paper award at the International Conference on Industry 4.0 and Smart Manufacturing (ISM2023) conference, Lisbon [5].

Data Availability Statement: No data are available.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Koren, Y.; Heisel, U.; Jovane, F.; Moriwaki, T.; Pritschow, G.; Ulsoy, G.; Van Brussel, H. Reconfigurable Manufacturing Systems. *CIRP Ann.* **1999**, *48*, 527–540. [CrossRef]
2. ElMaraghy, H.A. Flexible and reconfigurable manufacturing systems paradigms. *Int. J. Flex. Manuf. Syst.* **2006**, *17*, 261–276. [CrossRef]
3. Lupi, F.; Rocha, A.D.; Maffei, A.; Ferreira, P.; Barata, J.; Lanzetta, M. A Survey on Trends in Visual Inspection Systems Toward Industry 5.0. In Proceedings of the A Systematic Mapping Study, IEEE 30th International Conference on Engineering, Technology and Innovation (ICE 2024), Funchal, Portugal, 24–28 June 2024.
4. Lupi, F.; Freitas, N.; Arvana, M.; Rocha, A.D.; Maffei, A.; Barata, J.; Lanzetta, M. Next-generation Vision Inspection Systems: A Pipeline from 3D Model to ReCo File. *J. Intell. Manuf.* 2024, *in press*. [CrossRef]
5. Lupi, F.; Maffei, A.; Lanzetta, M. CAD-based Autonomous Vision Inspection Systems. *Procedia Comput. Sci.* **2024**, *232*, 2127–2136. [CrossRef]
6. Lupi, F.; Biancalana, M.; Rossi, A.; Lanzetta, M. A framework for flexible and reconfigurable vision inspection systems. *Int. J. Adv. Manuf. Technol.* **2023**, *129*, 871–897. [CrossRef]
7. Lupi, F.; Pacini, A.; Lanzetta, M. Laser powder bed additive manufacturing: A review on the four drivers for an online control. *J. Manuf. Process.* **2023**, *103*, 413–429. [CrossRef]
8. Quintanilla, F.G.; Cardin, O.; L'anton, A.; Castagna, P. A modeling framework for manufacturing services in Service-oriented Holonic Manufacturing Systems. *Eng. Appl. Artif. Intell.* **2016**, *55*, 26–36. [CrossRef]
9. Kusiak, A. Service manufacturing: Basic concepts and technologies. *J. Manuf. Syst.* **2019**, *52*, 198–204. [CrossRef]
10. Chiera, M.; Lupi, F.; Rossi, A.; Lanzetta, M. Lean Maturity Assessment in ETO Scenario. *Appl. Sci.* **2021**, *11*, 3833. [CrossRef]

11. Maffei, A. Characterisation of the Business Models for Innovative, Non-Mature Production Automation Technology. Doctoral Dissertation, KTH Royal Institute of Technology, Stockholm, Sweden, 2012.
12. Buerkle, A.; Eaton, W.; Al-Yacoub, A.; Zimmer, M.; Kinnell, P.; Henshaw, M.; Coombes, M.; Chen, W.-H.; Lohse, N. Towards industrial robots as a service (IRaaS): Flexibility, usability, safety and business models. *Robot. Comput. Manuf.* **2023**, *81*, 102484. [CrossRef]
13. Breschi, S.; Malerba, F.; Orsenigo, L. Technological Regimes and Schumpeterian Patterns of Innovation. *Econ. J.* **2000**, *110*, 388–410. [CrossRef]
14. Teece, D.J. Business Models, Business Strategy and Innovation. *Long Range Plan.* **2010**, *43*, 172–194. [CrossRef]
15. Chesbrough, H.; Rosenbloom, R.S. The role of the business model in capturing value from innovation: Evidence from Xerox Corporation's technology spin-off companies. *Ind. Corp. Change* **2002**, *11*, 529–555. [CrossRef]
16. DaSilva, C.M.; Trkman, P. Business Model: What It Is and What It Is Not. *Long Range Plan.* **2014**, *47*, 379–389. [CrossRef]
17. Osterwalder, A.; Pigneur, Y.; Bernarda, G.; Smith, A. *Value Proposition Design: How to Create Products and Services Customers Want*; John Wiley & Sons: Hoboken, NJ, USA, 2014; ISBN 978-1-118-96805-5.
18. Industry 5.0—Towards a Sustainable, Human-Centric and Resilient European Industry—European Commission. Available online: https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications/industry-50-towards-sustainable-human-centric-and-resilient-european-industry_en (accessed on 22 April 2024).
19. Porter, M.E. Competitive strategy. *Meas. Bus. Excell.* **1997**, *1*, 12–17. [CrossRef]
20. Osterwalder, A. The Business Model Ontology a Proposition in a Design Science Approach. 2004. Available online: https://www.academia.edu/download/30373644/thebusinessmodelontology.pdf (accessed on 17 April 2024).
21. Bocken, N.M.P.; Short, S.W.; Rana, P.; Evans, S. A literature and practice review to develop sustainable business model archetypes. *J. Clean. Prod.* **2014**, *65*, 42–56. [CrossRef]
22. Brändström, J.; Eriksson, O. How circular is a value chain? Proposing a Material Efficiency Metric to evaluate business models. *J. Clean. Prod.* **2022**, *342*, 130973. [CrossRef]
23. Pacini, A.; Lupi, F.; Rossi, A.; Seggiani, M.; Lanzetta, M. Direct Recycling of WC-Co Grinding Chip. *Materials* **2023**, *16*, 1347. [CrossRef] [PubMed]
24. Chaubey, R.; Sahu, S.; James, O.O.; Maity, S. A review on development of industrial processes and emerging techniques for production of hydrogen from renewable and sustainable sources. *Renew. Sustain. Energy Rev.* **2013**, *23*, 443–462. [CrossRef]
25. Lupi, F.; Cimino, M.G.C.A.; Berlec, T.; Galatolo, F.A.; Corn, M.; Rožman, N.; Rossi, A.; Lanzetta, M. Blockchain-based shared additive manufacturing. *Comput. Ind. Eng.* **2023**, *183*, 109497. [CrossRef]
26. Huang, Y.; Qian, L.; Soopramanien, D.; Tyfield, D. Buy, lease, or share? Consumer preferences for innovative business models in the market for electric vehicles. *Technol. Forecast. Soc. Change* **2021**, *166*, 120639. [CrossRef]
27. Nijhof, A.; Schaveling, J.; Zalesky, N. Business, society, and the need for stewardship orientation. *J. Organ. Change Manag.* **2019**, *32*, 145–163. [CrossRef]
28. Bocken, N.; Short, S. Towards a sufficiency-driven business model: Experiences and opportunities. *Environ. Innov. Soc. Transit.* **2016**, *18*, 41–61. [CrossRef]
29. Koren, Y. General RMS characteristics. comparison with dedicated and flexible systems. In *Reconfigurable Manufacturing Systems and Transformable Factories*; Springer: Berlin/Heidelberg, Germany, 2006; pp. 27–45. [CrossRef]
30. Morgan, J.; Halton, M.; Qiao, Y.; Breslin, J.G. Industry 4.0 smart reconfigurable manufacturing machines. *J. Manuf. Syst.* **2021**, *59*, 481–506. [CrossRef]
31. Boffa, E.; Maffei, A. Development and application of an Integrated Business Model framework to describe the digital transformation of manufacturing—A bibliometric analysis. *Prod. Manuf. Res.* **2023**, *11*, 2164952. [CrossRef]
32. Amit, R.; Zott, C. Value creation in E-business. *Strat. Manag. J.* **2001**, *22*, 493–520. [CrossRef]