Proceedings of the 35th European Safety and Reliability & the 33rd Society for Risk Analysis Europe Conference
Edited by Eirik Bjorheim Abrahamsen, Terje Aven, Frederic Bouder, Roger Flage, Marja Ylönen
 Published by Research Publishing, Singapore.
doi: 10.3850/978-981-94-3281-3_ESREL-SRA-E2025-P8112-cd

Developing A Business Model For Sustainable Additive Manufacturing In The Oil & Gas Industry

Mandana Jorshari

Department of Life Cycle Management, Moreld Apply, Norway. E-mail: mandana.jorshari@apply.no

Jawad Raza

Department of Life Cycle Management, Moreld Apply, Norway. E-mail: jawad.raza@apply.no

The oil and gas industry faces mounting pressure to adopt sustainable practices due to its significant environmental impact, including greenhouse gas emissions and resource depletion. Additive Manufacturing (AM), or 3D printing, offers a transformative solution by minimizing material usage and reducing emissions through localized production. This study aims to develop a sustainable and economically viable business model to integrate AM into the oil and gas value chain. Using insights gathered via the Delphi method, including expert opinions from industry specialists. The research evaluates the benefits of AM, such as improved operational efficiency, reduced waste, and supply chain optimization, while identifying the challenges of its adoption in the Norwegian oil and gas sector. Findings indicate that AM holds great potential to enhance sustainability, lower operational costs, and streamline the supply chain. This study provides strategic recommendations and case studies, presenting a framework for transitioning to sustainable manufacturing practices in the oil and gas industry through innovative business models.

Keywords: Additive Manufacturing (AM), Sustainability, Oil and Gas Industry, Business Model Canvas (BMC), Circular Economy.

1. Introduction

The oil and gas sector as a cornerstone of the global economy provides the essential energy that is required for modern life. However, its environmental repercussions, characterized by greenhouse gas (GHG) emissions, air pollution, and ecological degradation, have garnered attention in global sustainability discourse. According to the International Energy Agency (IEA, 2022),the transportation, refining, and extraction of fossil fuels comprise over 15% of global greenhouse gas emissions in 2022. Apart from carbon dioxide (CO_2), the industry generates sulfur oxides (SO_x), nitrogen oxides (NO_x), particulate matter (PM), and volatile organic compounds (VOCs), therefore endangering ecosystems and public health. Coupled with incidents like oil spills and wastewater mismanagement, the industry's environmental impact underscores an urgent need for change.

Due to growing public demand for sustainable practices and stricter regulatory attention, the industry must explore innovative technologies that align with sustainable development goals (SDGs). Additive Manufacturing (AM), also known as 3D printing, emerges as a transformative technology that could redefine operational efficiency while addressing sustainability challenges. It can reduce waste and carbon emissions by facilitating localized production, optimizing resource utilization, and decreasing dependence on supply chains. Its utilization in the oil and gas industry not only advances the Sustainable Development Goals of responsible consumption and industrial innovation but also facilitates just-in-time production, minimizes downtime, and lowers storage expenses.

This essay argues that the use of AM can facilitate a transformation in the manufacturing paradigm within the oil and gas sector. It also demonstrates how the analysis of the financial, environmental, and operational advantages of AM has the potential to address critical challenges, aids the sector in achieving its long-term objectives, could revolutionize the manufacturing sector, and elucidates its necessity as a strategic imperative in an increasingly scrutinized industry.

2. Research Phases

The aim of this study is to create an environmentally friendly and financially feasible commercial model for including AM into the gas and oil sector. To reach this, a qualitative approach has been used to identify obstacles and enablers of AM adoption by means of expert opinions gathered using the Delphi technique, which is a way of organized communication used to compile knowledge from a panel of business professionals (Dalkey and Helmer, 1963). Experts were selected based on their experience in AM, sustainability, oil and gas operations. The method involved iterative rounds of questionnaires in which comments were polished until an agreement was obtained (Hasson et al., 2000). Using thematic coding—where responses were arranged into repeating themes—obtained data were examined. This process enabled the identification of critical barriers, enablers, and best practices for integrating AM into the oil and gas value chain (Braun and Clarke, 2006).

Phase 1: Literature Review and Framework Development

An extensive literature review was conducted to understand the current state of AM adoption and sustainability practices in the oil and gas industry. This phase also involved identifying gaps in existing business models and theoretical frameworks.

Phase 2: Data Analysis, Validation and Refinement

Qualitative data was collected and analyzed in this phase. The proposed business model was validated and refined through expert feedback, ensuring its practicality and alignment with industry needs.

Ethical Considerations and Limitations

To ensure ethical compliance, participant confidentiality was maintained throughout the Delphi process. Data integrity was prioritized by using reliable sources and transparent analytical methods.

This study acknowledges certain limitations, including the potential biases inherent in expert opinions. Additionally, the findings are specific to the Norwegian oil and gas sector and may not be directly generalizable to other regions.

Literature Review

Sustainability

Sustainability has emerged as a cornerstone for industries seeking to balance economic development with the protection of the environment. Defined by the Brundtland Report as the ability to meet the needs of the present without compromising the future (Brundtland, 1985), it involves three key dimensions: economic, social, and environmental (Goodland, 1996). These dimensions interact with one another in dynamic balance, and the optimization of one will have an impact on the others (Kuhlman and Farrington, 2010). The "triple bottom line" model is a popular method of measurement of sustainability, with a focus on economic viability, social inclusiveness, and ecological conservation (Elkington, 1997).

While significant, the concept of sustainability is not without its criticisms. Kuhlman and Farrington argue that the existing interpretation obfuscates the inherent conflict between long-term sustainability and short-term welfare (Kuhlman and Farrington, 2010). They advocate for maintaining resources for future generations with an emphasis on sustainable action rather than a balance of competing interests. The United Nations Sustainable Development Goals (SDGs) also provide a model for global action toward sustainability with targets such as SDG 9 (Industry, Innovation, and Infrastructure) and SDG 12 (Responsible Consumption and Production) facilitating industrial action (Nations, 2015).

Additive Manufacturing (AM)

AM has transitioned from a prototyping tool to a disruptive technology, revolutionizing industries such as aerospace, automotive, and healthcare (Boparai et al., 2017). By building components layer by layer, AM minimizes material waste, enhances customization, and facilitates localized production, making it a sustainable alternative to conventional manufacturing (Khajavi et al., 2014).

AM has a number of benefits over conventional manufacturing, including reduced material waste, shorter development times, and greater design flexibility (Khajavi et al., 2014). Its facilitation of on-demand and local production reduces lead times and the requirement for conventional processes (Simons, 2018) and transportation emissions (Liu et al., 2017). Still, problems such as high material cost, restricted production rates, and quality control problems persist. Therefore, AM technology development is necessary to solve the problems and unlock its full potential (Simons, 2018).

Digital inventory systems make additive manufacturing more useful by having spare parts stored as digital files that can be made on demand. This cuts down on the need for physical inventory, shortens lead times, and lowers the cost of having too much or too little stock (Bang-Olsen and Aanestad, 2020). Chekurov et al. (Chekurov et al., 2018) give an example of a system in which the order is managed digitally, with easy integration among the AM service provider, the supplier, and the end-user. Despite its benefit, digital inventory is faced with the challenge of integrating with existing ERP systems as well as overcoming organizational resistance to the application of new technology (Bang-Olsen and Aanestad, 2020). Strategic efforts such as aligning the process of procurement with digital ecosystems have to be initiated in order to attain the full potential of digital inventory systems (Chekurov et al., 2018).

AM technologies involve a broad variety of materials, including polymers, composites, and metals (Boparai et al., 2017). Metal powders are particularly vital to industries requiring high-strength parts. Gas atomization and plasma atomization processes are used to produce metal powders of preferred characteristics, ensuring quality and performance. While metal powders offer advantages, their high cost remains a barrier to widespread adoption. However, green techniques of making metal powders, such as the use of recycled material, can reduce the cost and make the process eco-friendly (Aanestad and Szekel, 2023).

Business Models

In today's competitive environment, businesses must adopt innovative models to create stakeholder value and meet evolving customer demands. Business models that explain how companies create and capture value (Osterwalder and Pigneur, 2010) are key to the adoption of such revolutionary technologies as Additive Manufacturing that have the capability to revolutionize supply chains by enabling localized, on-demand production, reducing costs and environmental footprints (Chekurov et al., 2018).

Traditional models must evolve to integrate AM, leveraging such capabilities as digital inventory systems and distributed manufacturing to achieve competitive advantage. Current structures, such as Porter's Value Chain (Porter, 1985), the Four-Box Business Model (Johnson et al., 2008), and the Lean Startup Model (Ries, 2011), and many more provide directions but require dynamic modification to align with AM.

The
Business Model Canvas (BMC)(Osterwalder and Pigneur, 2010), with its nine building blocks, is particularly one of the effective tools to align AM with organizational goals. It is concerned with the delivery of unique value through customization (Chekurov et al., 2018), technological shift adjustment (Osterwalder and Pigneur, 2010), integration of sustainability (Aanestad and Szekel, 2023), and overcoming of the problems of decentralized production (Khajavi et al., 2014). Siemens' redesign of parts of a gas turbine (Siemens, 2017), as examples, demonstrates the capability of AM to cut costs and increase sustainability. Whereas BMC allows the integration of AM, the cost of material, quality management, and organizational resistance are issues that exist (Khajavi et al., 2014). However, overcoming these issues could reveal operational effectiveness and sustainability benefits.

3. Proposed Business Model:

BMC was used to integrate findings from the data analysis into a comprehensive framework. The BMC's blocks facilitated the visualization of key components, such as value propositions, customer segments, and cost structures, ensuring the model's relevance and applicability. See figure 1.

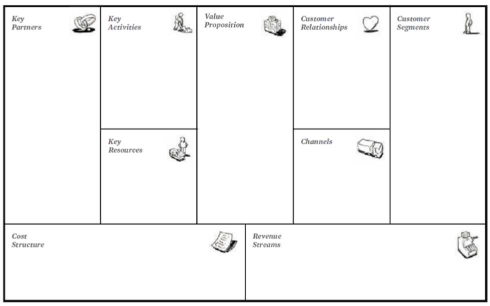

Fig. 1. Business Model Canvas.

3.1. *Delphi Round 1: Questions for the Business Model Canvas*

The first round of the Delphi process aimed to gather expert insights on each building block of the Business Model Canvas (BMC) (Osterwalder and Pigneur, 2010). The questions were designed to explore the potential of additive manufacturing in the oil and gas industry and identify opportunities and challenges associated with its adoption. Below, the questions for each building block are explained:

Customer Segments

The question for this building block focused on identifying the key customer groups for AM solutions within the oil and gas industry: *Who are the potential customers for additive manufacturing solutions in the oil and gas sector?* This question sought to define whether the primary customers are maintenance service providers, drilling companies, or equipment manufacturers. Understanding the unique needs of these segments, such as on-demand production or customization, is crucial for tailoring AM solutions.

Value Propositions

For the value proposition, the question asked: *What unique value does additive manufacturing provide to customers in the oil and gas industry?* This question aimed to uncover the benefits AM can deliver, such as reduced downtime, improved supply chain efficiency, cost savings, and contributions to sustainability efforts (Khajavi et al., 2014).

Channels

To determine the optimal delivery methods for AM solutions, experts were asked: *Through which channels can AM solutions be delivered to oil and gas customers?* This included exploring direct sales, partnerships with distributors, or online platforms as potential delivery mechanisms (Chekurov et al., 2018).

Customer Relationships

The question for customer relationships focused on the type of interaction and support required for AM adoption: *What type of relationship should the company establish and maintain with AM customers?* Responses were expected to distinguish between transactional relationships and long-term collaborations that involve customization and after-sales support (Bang-Olsen and Aanestad, 2020).

Revenue Streams

To explore revenue generation possibilities, the question was: *How can revenue be generated from integrating AM into the oil and gas industry?* This included models such as selling AM products, leasing equipment, offering on-demand services, or providing maintenance contracts (Simons, 2018).

Key Resources

The experts were asked: *What key resources are required to implement AM in the oil and gas value chain?* This question highlighted the need for skilled personnel, advanced AM machines, metal powders, and digital infrastructure (Aanestad and Szekel, 2023).

Key Activities

For key activities, the question asked: *What core activities are necessary to deliver value through AM?* This included actions like designing parts, sourcing materials, managing production, and maintaining AM technology (Khajavi et al., 2014).

Key Partnerships

To identify critical collaborators, the question was: *Who are the potential partners needed for successful AM implementation in oil and gas?* This building block explored partnerships with AM technology providers, material suppliers, logistics companies, and regulatory agencies (Osterwalder and Pigneur, 2010).

Cost Structure

Finally, the cost structure was addressed with the question: *What are the major costs associated with integrating AM into the oil and gas sector?* The experts identified costs related to AM machine acquisition, training programs, material sourcing, and energy consumption (Khajavi et al., 2014).

3.2. *Delphi Method: Final Round*

Expert opinions have been elicited in the Delphi process to construct an AM ecosystem diagram. Figure 2, presents a clear diagram of the system, its gaps as they currently exist, and the areas encompassed by the green boxes are the ones in which the subject firm can operate most effectively. The AM ecosystem diagram illustrates the interactions between the various elements and highlights the dynamic interaction between external and internal elements that drive the business case of delivering printed parts to the end-user and generating revenue. The diagram divides the ecosystem into three main groups:

The chart categorizes the ecosystem into three main groups:

3.2.1. *External factors*

represent the broader environment that affects the AM ecosystem beyond organizational boundaries. They are influential in that they determine the business environment for AM companies including market dynamics, regulatory requirements, and the overall support for AM technologies.

- *Demand*: The market's need for AM products and services, which drives growth and innovation in the sector.
- *Regulations*: Legal and regulatory frameworks that outline compliance standards for AM technologies.
- *Policies and Incentives*: Governmental or organizational measures designed to encourage the adoption and advancement of AM technologies, such as tax breaks or grants.
- *Initiatives*: Specific programs or actions aimed at fostering the development and expansion of AM technologies.
- *Market Acceptance*: The readiness and willingness of the market to embrace and integrate AM products and services, influencing their adoption rate and overall success.

3.2.2. *AM Ecosystem: Internal Factors*

Internal factors are within the organization's direct control and are critical for the successful implementation of AM. These include strategic decisions, financial evaluations, and risk management practices, ensuring that AM aligns with the organization's capacity, goals, and long-term sustainability.

- *Identify Applications*: The first step is determining where AM can deliver significant benefits over traditional methods. This involves assessing potential applications, identifying their cost-effectiveness, and ensuring AM fits the organization's needs. If AM is not viable, alternative solutions should be explored to optimize resource utilization.
- *Evaluate Cost-Effectiveness*: A thorough analysis of the costs and benefits is essential. AM must justify its economic value through cost savings, efficiency gains, or added value. If not initially cost-effective, optimization measures like improved processes, better material pricing, or scaling production should be considered.
- *Risk Management*: Effective risk management identifies and mitigates potential challenges associated with AM adoption. This ensures financial stability and operational success while aligning AM initiatives with sustainability

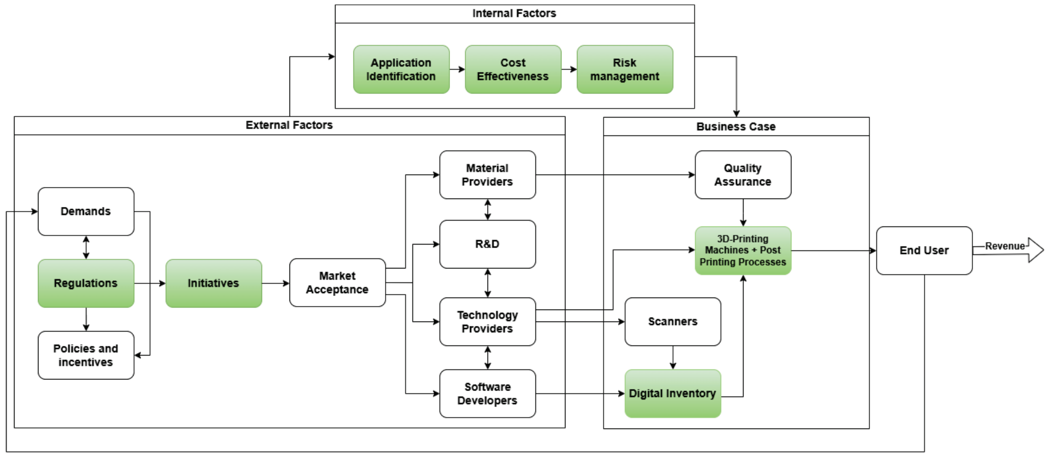

Fig. 2. AM Ecosystem Chart for the subject company

goals. If risks cannot be adequately mitigated, strategies like project adjustments or additional safety measures should be implemented.

3.2.3. *AM Ecosystem: Business Case*

The business case for Additive Manufacturing emerges when internal and external factors align to create a strong foundation for investment and operational implementation. Proper management of these factors ensures AM can deliver significant returns on investment and drive operational efficiency.

- *Digital Inventory Systems*: These software solutions store 3D models and track physical inventory availability. By enabling just-in-time production and reducing lead times for part procurement, digital inventories enhance operational efficiency, minimize delays, and ensure continuous part availability.
- *3D Scanners*: Essential for creating accurate 3D models of parts no longer in production or unavailable in digital form. Though costly, 3D scanners save time and resources by eliminating the need for manual modeling and ensure precise replication of parts, adding value to the AM process.
- *Quality Assurance*: Focuses on maintaining high standards for input materials and final products. Ensuring the quality of metal powders and conducting rigorous post-production checks helps deliver reliable, high-quality products that meet industry standards, safeguard the organization's reputation, and boost customer satisfaction.
- *3D Printing Equipment and Post-processing*: Investments in advanced printing technology and efficient post-printing processes ensure high-quality outputs, reduced production times, and cost-effectiveness. These aspects justify AM's adoption for long-term growth and innovation.
- *End Users and Revenue Generation*: The ultimate goal is to produce innovative, customized products that meet customer demands and drive revenue. Successful AM implementation creates new market opportunities, enhances customer satisfaction, and validates the business case by showcasing its potential for profitability and growth.

By leveraging insights from the AM ecosystem and aligning strategies with industry best practices, companies can address market gaps and strengthen their position in the AM landscape. The proposed model (See Fig.) highlights these opportunities and provides a roadmap for maximizing AM's benefits.

4. Dicussion

This study brings to light AM's disruptive potential in industrial asset management, particu-

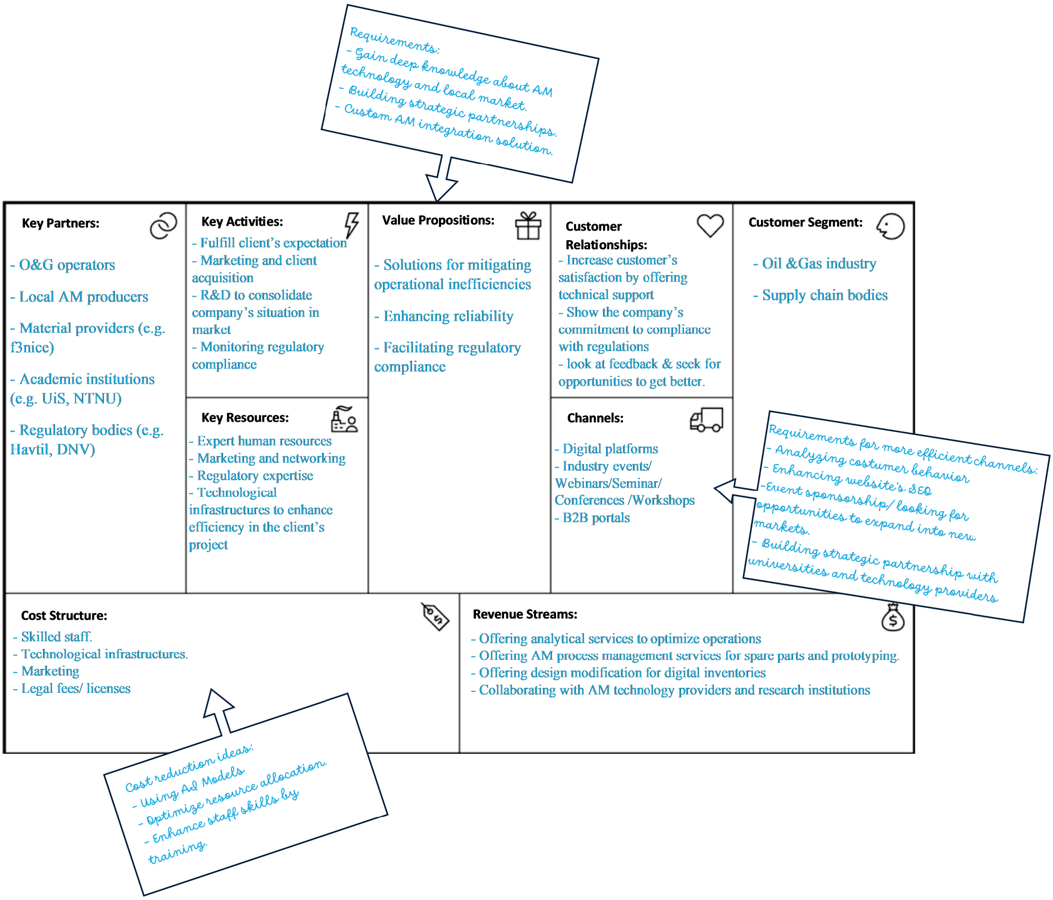

Fig. 3. Proposed Business Model for the subject company

larly in addressing economic and environmental issues. As AM transitions from a rapid prototyping tool to a disruptive technology, its advantages—material efficiency, design flexibility, on-demand production, production and supply chain optimization, waste reduction, and emission reduction—position it as a key enabler of sustainability. However, there are obstacles in the form of high up-front costs, material and expertise limitations, and quality control challenges that need to be addressed through strategic initiatives.

For Moreld Apply, a newcomer to the AM market, uncertainty is even more highlighted, despite being an inherent challenge in AM adoption. While expected costs provide a foundation on which to invest, relying solely on them may lead to inaccurate predictions. Shifting regulation and rapid technological advancements introduce variability to be accounted for. Scenario planning and exploring strategic alliances, can help to minimize the negative consequences—a strategy categorized under risk management, as depicted in Fig. 2.

In conclusion, Moreld Apply should focus on investing in areas of the AM ecosystem that align with its existing resources and capabilities. Once key focal points are identified, the proposed business model offers a structured framework that can guide further strategic decision-making and implementation.

References

Aanestad, H. and N. Szekel (2023). Profitability and sustainability of metal powder production for additive manufacturing in norway. *Journal of Sustainable Manufacturing 14*(1), 23–34.

Bang-Olsen, K. and H. Aanestad (2020). Digital inventory solutions for additive manufacturing: Frameworks and real-world applications. *Technologies 8*(2), 45–56.

Boparai, K. S., R. Singh, and S. Gill (2017). Current challenges and future directions of additive manufacturing in the aerospace sector. *Progress in Additive Manufacturing 2*(1), 19–42.

Braun, V. and V. Clarke (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology 3*(2), 77–101.

Brundtland, G. H. (1985). World commission on environment and development. *Environmental policy and law 14*(1), 26–30.

Chekurov, S., S. Metsä-Kortelainen, M. Salmi, I. Roda, and A. Jussila (2018). The perceived value of additively manufactured digital spare parts in industry: An empirical investigation. *International Journal of Production Economics 205*, 87–97.

Dalkey, N. and O. Helmer (1963). The delphi method: An experimental study of group opinion. *Futures 1*(5), 408–426.

Elkington, J. (1997). *Cannibals with forks: the triple bottom line of 21st-century business*. Capstone.

Goodland, R. (1996). Environmental sustainability: universal and non-negotiable. *Ecological Applications 6*(1), 19–26.

Hasson, F., S. Keeney, and H. McKenna (2000). The delphi technique: A critique. *Journal of Advanced Nursing 32*(4), 1008–1015.

IEA (2022). World energy outlook 2022.

Johnson, M. W., C. M. Christensen, and H. Kagermann (2008). Reinventing your business model. *Harvard Business Review 86*(12), 57–68.

Khajavi, S. H., J. Partanen, and J. Holmström (2014). Additive manufacturing in the spare parts supply chain. *Computers in Industry 65*(1), 50–63.

Kuhlman, T. and J. Farrington (2010). What is sustainability? *Sustainability 2*(11), 3436–3448.

Liu, P., S. H. Huang, A. Mokasdar, and H. Zhou (2017). Evaluation of additive manufacturing: Sustainability implications in the context of industry 4.0. *Journal of Cleaner Production 142*, 909–936.

Nations, U. (2015). Transforming our world: the 2030 agenda for sustainable development. Retrieved from `https://www.un.org/sustainabledevelopment/`.

Osterwalder, A. and Y. Pigneur (2010). *Business model generation: A handbook for visionaries, game changers, and challengers*. John Wiley & Sons.

Porter, M. E. (1985). *Competitive advantage: Creating and sustaining superior performance*. Free Press.

Ries, E. (2011). *The lean startup: How today's entrepreneurs use continuous innovation to create radically successful businesses*. Crown Publishing Group.

Siemens (2017). Siemens and e.on reach milestone with 3d-printed burner for sgt-700 gas turbine. Retrieved from `https://press.siemens.com/global/en/pressrelease`.

Simons, M. (2018). Additive manufacturing—a revolution in progress? insights from a multiple case study. *International Journal of Advanced Manufacturing Technology 96*(1-4), 735–749.