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BUILDING INFORMATION MODELING (BIM) AND LEAN 4.0 TO IMPLEMENT CIRCULAR ECONOMY IN THE OIL AND GAS SECTOR

Thesis presented to the Post Graduation program in Sustainable Management Systems of Federal Fluminense University as partial fulfillment of the requirements for the Doctoral degree (Ph.D.) in Sustainable Management Systems in the Applied Technologies for Sustainable Organizations

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ABSTRACT

This thesis aims to develop a sustainable management system that explore BIM and Lean 4.0 best practices to propose a circular supply chain in the oil and gas industry. Thus, the present PhD thesis proposes in its first published article a recycling 4.0 conceptual factory, starting from a wide investigation in the literature, interviews and documents to obtain a diagnosis with improvement opportunities, aiming to build sustainable management systems. In addition, the second article published is a planning of a routine management for work processes continuous improvement. Above all, a management model is proposed that uses BIM functionalities and Lean principles through an empirical study of an oil refinery scheduled maintenance shutdown for efficiency and reduction of waste, considering the need for asset replacement or repair of components inherent to the analyzed industrial plant. These assets are potential candidates to participate in a circular economy with the recycling factory 4.0 proposed in the first article published, integrating their waste into the value chain and into a new business model that recycles industrial components to support the resolution of a socio-economic development of the industry. Besides, once the main objective is to develop a sustainable supply chain, considering the synergies between Lean, BIM, Industry 4.0 and Sustainability, the third article of this thesis is a diagnosis in the oil and gas industry to identify opportunities for improving the processes that guide the creation of a Lean Six Sigma model for operations management. Finaly, the fourth article integrates the models proposed in the previous articles and proposes an interdisciplinary Lean management system model, called Circular Value Stream Mapping (CVSM) that is applied with well-known experts in BIM, Lean and Circular Economy (CE). Therefore, with the objective of evaluating the proposed construct through the perception of the public of interest, experts from the oil and gas industry participated in focus group events to analyze feasibility of implementation of the proposed model and highlight points of attention. The research methodology explores interdisciplinarity through an empirical study that uses the triangulation between documents, literature and focus groups to propose a new business model that aims to adapt the value chain, seeking to technically make feasible a recycling factory 4.0.

Keywords: Lean Six Sigma, Oil and Gas, Continuous Improvement, Circular Economy, Additive Manufacturing, Industry 4.0, Manufacturing Sector, Sustainable Supply Chain, Interdisciplinary, Building Information Modeling, Facility Management.

RESUMO

Esta tese visa desenvolver um sistema de gerenciamento sustentável que explore as melhores práticas de BIM e Lean 4.0 para propor uma cadeia de suprimentos circular no setor de óleo e gás. Assim, propõe em seu primeiro artigo publicado uma fábrica conceitual de reciclagem 4.0, a partir de uma ampla investigação na literatura, entrevistas e documentos para obter um diagnóstico, visando a construção de sistemas de gestão sustentável. Além disso, o segundo artigo publicado adiciona o planejamento nD de uma gestão de rotina para a melhoria contínua dos processos de trabalho. Sobretudo, é proposto um modelo de gestão que utiliza as funcionalidades BIM e os princípios Lean por meio de um estudo empírico de uma parada programada para manutenção em uma refinaria de petróleo, considerando a necessidade de substituição ou reparo de componentes inerentes à planta industrial analisada. Esses ativos são potenciais candidatos a participar de uma economia circular com a fábrica de reciclagem 4.0 proposta no primeiro artigo publicado, integrando seus resíduos na cadeia de valor e em um novo modelo de negócios que recicla componentes industriais para apoiar a resolução de um desenvolvimento socioeconômico da indústria. Além disso, uma vez que o principal objetivo é desenvolver uma cadeia de suprimentos sustentável, considerando as sinergias entre Lean, BIM, Indústria 4.0 e Sustentabilidade, o terceiro artigo realiza um diagnóstico no setor de óleo e gás para identificar oportunidades de melhoria nos processos em prol da criação de um modelo Lean Six Sigma para gerenciamento de operações. Por fim, o quarto artigo integra os modelos propostos nos artigos anteriores e propõe um modelo interdisciplinar de sistema de gerenciamento BIM e Lean 4.0, denominado Circular Value Stream Mapping (CVSM), avaliado por especialistas representativos em BIM, Lean 4.0 e Circular Economy (CE). Portanto, com o objetivo de avaliar o construto proposto por meio da percepção do público de interesse, especialistas do setor de óleo e gás participaram de eventos para analisar a viabilidade da implementação do modelo proposto. A metodologia de pesquisa explora a interdisciplinaridade por meio de um estudo empírico que utiliza a triangulação entre documentos, literatura e grupos focais para propor um novo modelo de negócios que visa adaptar a cadeia de valor, propondo um sistema de gestão sustentável BIM e Lean 4.0 em prol da implantação da economia circular no setor de óleo e gás.

Palavras-chave: Lean Six Sigma, Setor de Óleo e Gás, Melhoria Contínua, Economia Circular, Manufatura Aditiva, Industria 4.0, Setor de Manufatura, Cadeia de Suprimentos

Sustentáveis, Gestão Interdisciplinar, Building Information Modeling (BIM), Gestão de Instalações.

ABOUT THE PAPERS

The articles in this doctoral thesis on sustainable management systems explore several different topics within the technologies for sustainable organizations area, with the aim of deploying a Lean system with industry 4.0 and BIM practices to achieve a circular economy in the oil and gas sector. The motivation for research on the core theme comes from waste along the oil and gas operators value chain, considering exploring a new opportunity to recirculate materials that can be worked on to generate new high value-added products. The articles complement each other to form a sustainable supply chain that monitors and controls the operations management and facilities of industrial plants to connect a new circular system. Therefore, the present thesis is based on the following articles:

I. **Exploring Industry 4.0 Technologies to Enable Circular Economy Practices in a Manufacturing Context: A Business Model Proposal**

Nascimento, D., Alencastro, V., Quelhas, O., Caiado, R., Garza-Reyes, J., Rocha-Lona, L. and Tortorella, G. (2019), *Journal of Manufacturing Technology Management*, Vol. 30 No. 3, pp. 607-627. https://doi.org/10.1108/JMTM-03-2018-0071

II. **Facility Management using Digital Obeya Room Model by Integrating BIM-Lean Aproaches for Continuous Improvement – An Empirical Study**

Nascimento, D. L. de M., Quelhas, O. L. G., Meiriño, M. J., Caiado, R. G. G., Barbosa, S. D. J., & Ivson, P. (2018), *Journal of Civil Engineering and Management*, 24(8), 581-591. https://doi.org/10.3846/jcem.2018.5609

III. **Lean Six Sigma Three-Dimensional Framework for Continuous and Incremental Improvement in the Oil and Gas Sector**

Nascimento, D.L.M; Quelhas, O.L.G; Caiado, R.G.G; Tortorella, G.L; Garza-Reyes, J.A; Rocha-Lona, L. (2019), *International Journal of Lean Six Sigma*. https://doi.org/10.1108/IJLSS-02-2019-0011

IV. **BIM and Lean 4.0 Circular Approach to Improve Triple Bottom Line in Sustainable Management Systems**

Nascimento, D.L.M and Quelhas, O.L.G (2019), *Journal of Civil Enginnering and Managment*, submitted for publication.

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LIST OF ABBREVIATIONS

AD	Anderson-Darling
DMAIC	Define-Measure-Analyze-Improve-Control
GDP	Gross Domestic Product
GLSS	Green Lean Six Sigma
GRI	Global Reporting Initiative
GSCM	Green Supply Chain Management
HR	Human Resources
KPIs	Key Performance Indicators
KS	Kolmogorov-Smirnov
LCA	Life Cycle Assessment
LM	Lean Manufacturing
LS	Lean Services
LSS	Lean Six Sigma
LT	Lean Thinking
MDGs	Millennium Development Goals
PDCA	Plan-Do-Check-Act
SD	Sustainable Development
SDGs	Sustainable Development Goals
TBL	Triple Bottom Line
VSA	Value Stream Analysis
VSM	Value Stream Mapping
TPM	Total Productive Maintenance
BIM	Building Information Modeling

CONTENTS

1 INTRODUCTION

Industry 4.0 is a concept that is increasingly being explored by companies, research institutions, and it is closely related to the advancement of information and communication technologies as well as data storage. From this, joined with a continuous improvement methodology based on deployment in workflows of the following technologies: internet of things, augmented reality, additive manufacturing, big data, cloud computing, general simulations, and industrial automation and cyber security (Trompisch, 2017; Wagner et al., 2017; Barreto et al., 2017; Li and Yang, 2017; Nascimento et al. 2019).

There is great expectation, both in the scientific and business environments, that these new technologies will permeate the most varied production chains and the service sector (Wood et al., 2014; Tortorella et al. 2019). A number of researches have already been published dealing with Industry 4.0, proposing different scenarios and benefits of its implementation. Some authors such as Kang et al. (2016); Zhou et al. (2016); Wan et al. (2016a); Ivanov et al. (2016); Wollschlaeger et al. (2017); Lom et al. (2016); Thoben et al. (2017); Caiado et al. (2019) suggest that such technologies enable efficiency gains, as well as the possibility of better control over operation data and energy expenditures of machines and processes. In addition, Liu and Xu (2017); Baccarelli et al. (2017); Schumacher et al. (2016) affirm those technologies increase productivity due to greater optimization and simulation capabilities. However, emphasizing the necessity of using big data and interoperability approaches between applications (Hortelano et al., 2017; Wan et al., 2016b; Niesen et al., 2016; Foidl and Felderer, 2016).

Customization of products and production on demand are also results pointed out by some researches (Wan et al., 2016b; Wang et al., 2017; Li et al., 2017). More broadly, there is the expectation of social change due to transformations in the work environment, and the possibilities for communication and entertainment that emerge from the new digital technologies and are likely to bring cultural impacts. Amidst so many promises of change, considering the proportion of expected impacts of such technologies on society and economy, it is necessary to investigate the effects of Industry 4.0 on environmental aspects. Such aspects tend to be neglected throughout the changes involved in the evolution of industry (Shrouf et al., 2014; Stock and Seliger, 2016; Prause, 2015; Einsiedler, 2013; Ivanov, 2018; Quezada et al., 2017).

One of the main problems faced by the manufacturing sector nowadays is managing several resources in an interdisciplinary and integrated way. Several studies in production planning and control have been carried out on Lean Thinking (Khadem et al. 2008; Romero, Martín 2011; Chong et al. 2013; Serrano 2016) in order to decrease waste and lead time, improve productivity and efficiency, and add value to operations. Analogously in the industrial plant construction sector has a dispersed discipline management method, this sector has the necessity to adapt processes and procedures aiming a more integrated approach to harmonize technology and people toward strategic goals. According to Sacks et al. (2010), Lean Thinking, as well as BIM has the potential to remarkably change Architecture, Engineering, Construction and Operation (AECO). Within the last twenty years, both methodologies became innate attributes of the project in engineering processes, aiming to improve documentation quality as well as predictability (Wang et al. 2013; Yang, Ergan 2016; Shalabi, Turkan 2017).

Industrial plant construction projects have a very iterative and changeable structure, leading to constant design changes. Their composition and formation are not constant or fixed; they are continuously changing. Modifications are not restricted to design phases, they can happen after the construction starts, especially regarding fast-track projects. Therefore, management changes are fundamental for efficient accomplishment of industrial construction projects. Given that, BIM is a powerful tool to support an integrated lifecycle management, from the design phase to operation, based on a smoother coordination process (Pilehchian et al. 2015; Mohamad 2016). Building Information Modeling has impact on short term – driving productivity and quality toward higher levels – and encourage bigger changes in processes related to management, as it provides tools to coordinate a substantial amount of information, a main principle of Lean Production (Womack, Jones 2003).

Gallaher et al. (2014) by the National Institute of Standards and Technology (NIST), an U.S. Department of Commerce laboratory, states that losses in the oil and gas industry are associated with failures in the integration of engineering tools. Problems related to interoperability in information flows and systems structures caused a US$ 15.8 billion dollars a year debt. Dave et al (2015) claims that to encourage unification among processes, technologies and people, synergies between Lean methodology and BIM are mandatory. Summarizing, Lean Thinking is a methodology that aims reductions towards enhancement: fewer equipment, space, staff and human efforts to achieve better results related to the real needs of the clients. As a result, more efficient processes leads to less waste, generating better customer values (Comm, Mathaisel 2006).

Lean Thinking and BIM, according to Sacks et al. (2010), are nonrelated initiatives and, in the current stage of both, probably, professional and companies are still in the beginning of the learning curve in each approach. Meanwhile, if their synergy is properly understood, both methodologies can be explored in favor of improving engineering and AEC processes. Otherwise, Arayici et al. (2011) states that implementation of BIM in companies still faces challenges. The main reasons to stall larger adoption is lack of orientation or practical studies to support users and drive improvements in knowledge regarding BIM. Consequently, it reduces improvements in productivity, efficiency and quality.

Since the oil crisis in 1973, the high cost and scarcity of petroleum products has generated a number of challenging side effects, especially in industries correlated with this supply chain (Ang, 2001; Newiadomsky & Seeliger, 2016). This fact has led organizations to seek political and economic solutions, whether by lobbying the Organization of the Petroleum Exporting Countries (OPEC), monitoring oil companies for energy-conscious consumption or making governments adjust their taxes, tariffs and quotas. In this sense, the development of techniques for waste reduction, such as just-in-time (JIT) production, was reinforced by this context, thus increasing the adoption level of these practices (Schonberger, 1982; Deithorn & Kovach, 2018). Näslund (2013) states that after the oil crisis the Japanese term JIT came to be widely discussed as a more creative alternative to suit the economic recession. Currently, the oil and gas industry faces major challenges, such as: shrinking conventional oil reserves, environmental challenges, stricter regulations, higher production costs and a drop in the price of barrel (Reboredo, 2010; Reboredo & Rivera-Castro, 2014). These challenges motivate its agents to seek ways to optimize their operations, improve their cash flow and avoid waste. Among the management approaches applied, the continuous improvement principle that underlies the LP and Six Sigma stands out (Mustapha et al., 2015). Both approaches are widely used in industry, especially manufacturing, however, in the scientific literature there are few examples of the application of its principles in the oil and gas sector (Nascimento et al. 2017; Ivson et al. 2018).

According to Maleyeff et al. (2012), LP aims to reduce waste through the engagement and empowerment of employees, suppliers and customers. In addition, LP promotes continuous improvement of products, processes and services, through a structured problem-solving methodology (Tortorella et al. 2018). Analogously, Six Sigma seeks to reduce errors and defects by applying the DMAIC methodology comprised by the steps: (i) Define, (ii) Measure, (iii) Analyze, (iv) Improve and (v) Control (Buell & Turnipseed, 2003). Therefore, both approaches highlight the importance of reducing costs and maximizing profit in organizations by developing quality products or services (Sunder & Antony, 2015).

However, there is lack of research about the integration of LP, PDCA and Six Sigma (DMAIC) in the oil and gas context (Bubsha and Al-Dosa, 2014; Ratnaya and Chaudry, 2016; AL-Riyami and Jabri, 2017; Deitho and Kovach, 2018), as well as empirical studies persuing the alignment between LP, PDCA Cycle and DMAIC methodology (Quelhas et al. 2017). In addition, its necessary to fill the gap concerning the lean culture and socio-technical aspects in organizations through operational improvements training (Tortorella, Vergara & Ferreira, 2016). A successful LP implementation depends on a series of practices and principles that have a high degree of interdependence and synergy (Fahmi and Hollingworth, 2012). The lack of understanding of this systemic characteristic by the top management leads to failures in adopting LP, since there may be a belief that with a partial implementation a large part of the benefits can be obtained (Shah and Ward, 2003). In this sense, a value stream involves any activity necessary to transform the raw material into finished product (Rother and Shook, 1999).

1.1 Objectives

1.1.1 General Objectives

The general objective of this thesis aims to verify in the literature of sustainable management systems and in the industry, opportunities for incremental and/or disruptive improvements to optimize work processes in the oil and gas industry. In addition, to develop sustanaible management system for operations and maintenance industrial plants facilities, since these assets generate waste to recycle components of industrial plants and connect to a new digital factory that allows to recycle or reuse these components, generating new products sustainable for society. A premise for all the management systems required in the value chain is the empirical evidence for evaluation in practice and validation of the maturity of implementation of each sustainable management model. Therefore, in order to achieve the general objective, a division of each management model necessary for the proposed sustainable supply chain is carried out, considering each specific objective in the following section, to publish three articles in international journals to compose the global model of circular economy that concerns the integrated supply chain of a digital waste factory.

1.1.2 Specific Objectives

Once the general objective of the research is develop a sustainable management system that explore BIM and Lean 4.0 best practices to propose a sustainable supply chain in the oil and gas industry, considering the contribution of each particular article to a global objective that proposes a methodologies and technologies in favor of this sustainable management systems, the specific objectives are detailed:

- Study I: The purpose of this paper is to investigate through the literature, documents and focus groups the new technologies of industry 4.0, analyzing the resulting data to propose a business model that allows implementing CE practices in the reuse and recycling of scrap or electronic waste that have already exceed their life-cycle. This model is divided into steps and substeps to reuse these materials as input to the 3D printer and generate products with higher added value. At the end, discussion is promoted on the model proposed by Focus Group Interviews (FGIs), as well as for the environmental, social-technical, and economical dimensions;
- Study II: This paper applies a methodology for interdisciplinary Facilities Management (FM) by alingments between Building Information Modeling (BIM) and Lean. Initially, the literature review of BIM, FM and Lean principles. Afterwards, the research applies the Digital Obeya Room Framework for improved FM and describes its application on a real-world case study. Lastly, the work presents a survey with specialists to assess the relevance of each BIM-Lean concepts and correlate their perceptions with the empirical results. The main collaborations of this work are: a conceptual framework that relates the PDCA (Plan-Do-Check-Act) cycle with BIM-Lean approaches; the identification of the most relevant BIM functionalies and Lean principles; and the real-world application of the framework procedures on FM;
- Study III: This article aims to explore synergies between Lean and Six Sigma methodologies, in order to propose a Lean Six Sigma (LSS) three-dimensional framework for continuous improvement. This model seeks to target the most relevant and/or prominent steps for applying the Six Sigma and Lean concepts in PDCA cycle. This research seeks to fill the gap in the lack of frameworks that integrate and combine the waste reduction and costs of LP principles with the quality and reduction of variability across the life-cycle; and
- Study IV: The objective is to make a diagnosis in the Circular Economy (CE) and VSM literature, discuss through focus groups and propose the VSM Circular model (CVSM) to implement Lean 4.0 practices in the context of a recycling plant. Further, it allows determining more reliable lead times, while provides means to focus on improvement opportunities related to a Lean 4.0 circular production system. This method contributes to systemically identify variables that jeopardize the value stream,

which is usually unseen through conventional VSM. The implications for literature focus on the proposition of a new conceptual model of a recycling plant that uses precepts of building information modelling (BIM), circular economy and Lean 4.0. In practice, the model extends the control mechanisms and entities of the current VSM, incrementing design and digital fabrication steps with metrics for each value chain step.

Considering contextualizing the complementarity of the works presented in the specific objectives in favor of a convergent general objective. In Figure 1, an analysis of the content presented in the four aggregated articles is performed, seeking to highlight the deliverables of each work in favor of the proposition of a digital supply chain.

Figure 1. PhD Thesis Articles for Sustainable Supply Chain

Above all, Figure 2 considers the implementation of a digital information flow (ISO

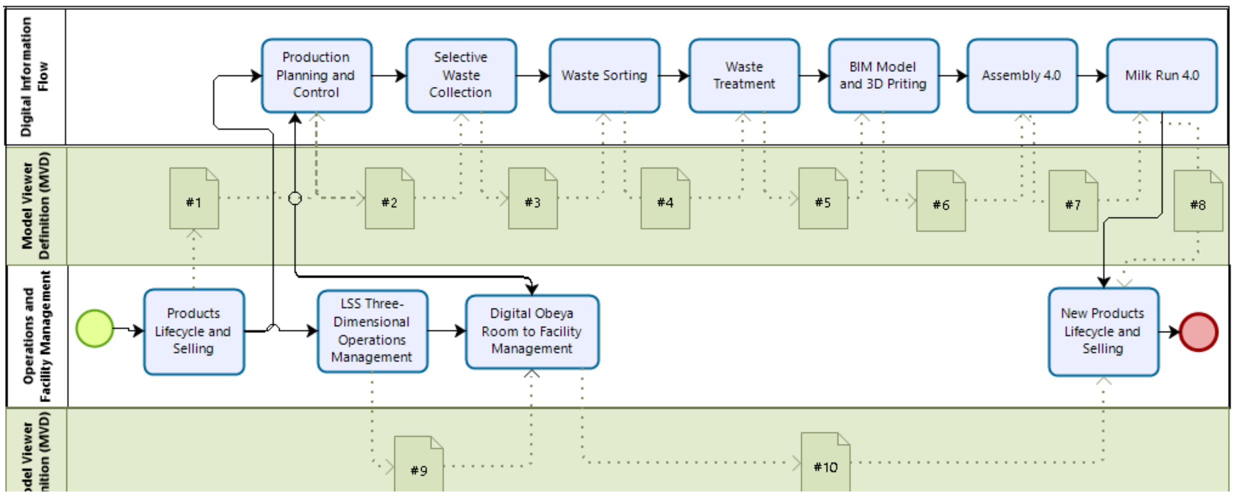


Figure 2. Information Delivery Manual (IDM) of Product from Published Articles

29481) that aggregates the results of the four articles in favor of a product, a BIM-Lean 4.0 digital factory focused on the implementation of CE practices.

The MVDs are detailed in the creation of the monitoring and control metrics developed in the fourth article, since it verifies the completeness and consistency of the information transferred in the workflow. After verification, mathematical calculations of control variables are performed to control efficiency and quality of the sustainable supply chain 4.0.

2 BACKGROUND

2.1 Transition Towards Circular Economy

The renowned definition of the Circular Economy (CE) has been framed by the Ellen MacArthur Foundation as "an industrial economy that is restorative or regenerative by intention and design" (2013b: 14). Many authors, like Lieder and Rashid (2016a); Geissdoerfer et al. (2017b); Despeisse et al. (2017); los Rios and Charnley (2017) attribute the introduction of the concept to Pearce and Turner (1990) in the 1990s when the term was first used to model an economy applying a materials balance model which follows the first and second law of thermodynamics. However, it was influenced by Boulding's (1966) work, which describes the earth as a closed and circular system with limited assimilative capacity where the economy and the environment should coexist in equilibrium (Geissdoerfer et al., 2017a). Thus, the concept of circularity has been emerging throughout the history and Circular Economy is now treated as an inevitable solution to series of challenges such as waste generation, resource scarcity and sustaining economic benefits (Lieder and Rashid, 2016b).

The principles underlining CE - that assume the planet as a closed system - are subject to the Laws of Thermo- dynamics that suggest the amount of resources depleted in a period is equal to the amount of waste generated in the same period (Genovese et al., 2017). According to Geissdoerfer et al. (2017a) CE is "a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops". However, Nakajima (2000) argues that circularity and service-based systems are not sufficient condition for sustainable manufacturing, Genovese et al. (2017) believes that circular economy is anessential element, and Rashid et al. (2013) even sees it as a precondition - if aligned with supply chains - to promote sustainable development.

Circular Economy can be achieved through long-lasting design, maintenance, repair, reuse, re-manufacturing, re- furbishing, and recycling and has some similarities with sustainability, such as the employment of interdisciplinary approaches to better integrate non-economic aspects into development, the need for cooperation of different stake- holders, the diversification in taking advantage of distinct opportunities for value creation and the importance given to system change and innovation Geissdoerfer et al. (2017a). Moreover, circular economy pushes the frontiers of environmental sustainability and is not just concerned with the delay of cradle-to-grave material flows as sustainable supply chain management (Genovese et al.,2017).

2.2 Sustainable Supply Chain Management

In parallel to the circular economy discourse, the emergence of sustainable supply chain management concepts has been developed and currently it has become a strategic process enabling firms to create competitive advantage by reducing unintended negative consequences on the environment of production and consumption processes, and the influence of sustainability in supply chain management and operations practices is gaining ground due to the fact that organizations are now held responsible for the environmental and social performance by major stakeholders (Genovese et al., 2017).

According to Rashid et al. (2013), closed-loop supply chains are considered as the most feasible solution to foster sustainable manufacturing strategies with resource and environment conservation and these closed-loop product systems usually include recycling, re-manufacturing or reuse chains as end-of-life (EoL) management strategies, applied at the end of product's useful life in order to improve environmental performance in the context of waste management.

2.3 Smart Production Systems

The 4th Industrial Revolution or Industry 4.0 refers to a strategy designed to construct a communication system between production equipment and products in a form of Connected Smart Factory (CSF), which refers to a hyper- connected network-based integrated manufacturing system that promotes the monitoring and autonomous control of all processes, replaces raw materials and prevents waste of materials and energy, adding values and convergence of products and services, as well as low-cost, high-variety and flexible production (Park, 2016).

Manufacturers attempt to enhance the competitiveness of companies by implementing CPS - a framework com- posed of different types of data acquisition/handling method, decision making rules and functions - through the convergence of IoT (Internet of Things) and ICT (Information and Communication Technology) in the manufacturing process level to make decision-making self-centeredly by using AI (Artificial Intelligence) Technologies (Lee et al., 2017). The new concept of production system in which CPS is called Smart Factory or CPPS (Cyber-Physical Production System). Thus, 3D printing and smart production systems emerge as a new manufacturing paradigm (Park, 2016).

2.4 Additive Manufacturing

Additive manufacturing (AM) is the process of producing objects from a three-dimensional (3D) model by joining materials layer by layer, directly from raw material in powder, liquid, sheet, or filament form without the need of molds, tools, or dies (Kellens et al., 2017). 3D printing technologies have certain advantages such as: making lateral moves less risky (products can be manufactured on demand with minimal costs), enabling firms to rapidly move upstream or downstream and to rapidly change the degree of vertical integration depending on the nature of the innovation considered and to enable business models to become modular and adaptable (Rayna and Striukova, 2016).

According to Kellens et al. (2017), there is a growing consensus that 3D printing technologies will be one of the next major technological revolutions and AM proposes a novel paradigm for engineering design and manufacturing,which has profound economic, environmental, and security implications.

2.5 Building Information Modeling (BIM) Functionalities

According to the glossary of the BIM Handbook written by Eastman, Teicholz, Sacks and Liston (2008), BIM is used as “a verb or adjective phrase to describe tools, processes and technologies that are facilitated by digital, machine-readable documentation about a building, its performance, its planning, its construction and later its operation. Therefore, BIM describes an activity, not an object. To describe the result of the modeling activity, we use the term ‘building information model’, or simply ‘building model’ in full”. Building Information Model has the potential to be the catalyst for project managers, in order to reengineer their process and to better integrate the various stakeholders of modern construction projects. This reengineering process can be a transition for effective applying Lean principles (Bryde et al., 2013).

Arayici et al. (2011) said that the implementation of BIM should have a bottom-up approach, rather than a top-down one, with regard to involve people in its implementation, to ensure the improvement in skills and the understanding of people to implement continuous improvement strategies, and to diminish any potential resistance to changes. According to the author, the seven pillars of a BIM implementation strategy are: to eliminate waste, to increase feedback, to analyze decisions until reaching a consensus, to fasten delivery, to build on integrity, to capacitate the team, and to see the whole.

On the other hand, Eastman et al. (2008) and Sacks et al. (2010) propose that for BIM to provide compilation, edition, evaluation and report of information regarding construction projects, the following technologies must be considered:

- 3D visualization (for aesthetics and functional assessment);
- Rapid generation of multiple design alternatives;
- Usage of model data for predictive analysis of the structure (performance, automated cost estimates, and evaluation of customer value conformity);
- Information maintenance and model integrity (single information source, automated conflict checking);
- Automatic generation of documents and drawings;
- Collaboration in the design and construction (multiuser editing of a single discipline model and multiuser visualization of multidisciplinary models, either separated or combined);
- Rapid assessment and generation of alternative construction plans alternatives (automatic generation of construction tasks, construction process simulation, 4D visualization of construction schedules);
- Online/electronic object-based communication (visualization of the process status, online communication of product and process information, computer controlled manufacturing process, integration with the database of the project partner-supply chain, context provision for status of data collection onsite/offsite);
- Automatic transference of information to support computer-controlled manufacturing processes.

The BIM functionalities presented by Eastman et al. (2008) and Sacks et al. (2010) should be evaluated in relation to the engineering systems required to support technologies, and also to the BIM maturity level of skills (knowledge, skills and attitudes). These features require a lean efficient and production management for sustainable development, in the section following within this context describes the principles and concepts of Lean Thinking.

2.6 Principles of Lean Thinking

For Aziz and Hafes (2013), since the 50's, Lean principles of the Toyota production system have evolved, and have been implemented successfully by the Toyota Motor Company. They were formed by two main conceptions: Just-in-Time flow (producing according to the demand) and Jidoka automation (man-machine separation, in which a single operator manages several machines). According to Villareal et al. (2012) the Lean Production is based on a philosophy of continuous improvement, where the search for the source and the reduction of waste is fundamental. The author defines seven forms of waste, activities that add cost but no value: production of goods not yet ordered; waiting; rectification of mistakes; excess processing; excess movement; excess transport; and excess stock.

Lean Construction has used the same concepts of Lean Production because both projects have the goal of reducing waste and increasing both productivity and efficiency in construction projects (Aziz and Hafes, 2013). Koskela (1992) developed an adaptation of the Lean Production concept for the construction industry and presented a new paradigm of production management, wherein the last can be conceptualized in three complementary ways: (1) Transformation, (2) Flow, and (3) Value generation (TFV). As the author states, Lean Thinking (LT) can be summarized in eleven principles. Later, Sacks et al. (2010) incremented four more principles:

- Variability reduction;
- Decrease of number of cycles;
- Reduction of sample size;
- Flexibility increase;
- Selection of an appropriate method of production control;
- Standardization;
- Institution continuous improvement;
- Visual management use;
- Production system design for value chain flow;
- Ensure comprehensive requirements capture;
- Focus on the concept selection;
- Guarantee operating flow requirements;
- Verification and validation;
- Go and see for yourself (Gemba);
- Decision by consensus, considering all options;
- Cultivation of an extensive network of partners.

It is possible to perceive some synergies between Lean principles and BIM functionalities. In the next section we evaluate related works that identified synergies between BIM and Lean.

2.7 BIM Applications for Facility Management

According to a study by the National Institute of Standards and Technology in the US, 85% of the life cycle cost of a facility occurs after construction (GCR NIST, 2004). Operations and maintenance phases are responsible for $10 billion in losses due to time-consuming information access and poor management practices. Despite this, BIM applications in Facility Management are still rare. A survey with professionals from different organizations found that only 42% of users employed it during operations and maintenance phases (Becerik-Gerber et al., 2012). According to the study, FM applications best supported by 3D CAD include: locating building components, facilitating real-time data access, visualization and marketing, checking maintainability, and space management.

Research by Patacas et al. (2015) investigated how BIM data standards could deliver asset information required by facility managers within a whole life cycle perspective. Results indicated many data requirements which were not satisfied by current industry standards and suggested best practices for smoother transition between design/construction phases and the facility management phase. Later work by Thabet and Lucas (2017) documented the real world challenges of adopting BIM for facility management. The pilot study highlighted the need for improvements in current management practices and traditional operational processes. Around the same time, Pishdad-Bozorgi (2017) called attention to the inefficiencies in current BIM solutions to meet facility management needs and requirements.

More recent research by Jang & Lee (2018) explored the impact of three organizational factors in BIM-based team coordination: number of participants, their heterogeneity, and the highest decision-maker involved. The coordination time linearly increased as each factor increased. The findings stressed the significance of integration between BIM and Lean approaches, such as Obeya (big room), to expedite decision-making processes and eventually to reduce the coordination time. Meanwhile, Wetzel et al. (2018) investigated the potential benefits of BIM for safety during facility management. The study proposed a Safety for Facilities Maintenance Framework that improved team communication and provided faster access to safety-critical information to FM personnel.

2.8 Synergies between BIM and Lean for Facility Management

Olatunji (2011) pursues that BIM has been associated with the development of Lean approaches for project management. This is especially true since BIM provides frameworks and technologies for an advanced collaboration and information sharing. As reported by Sacks et al. (2010), even though the concepts of Lean Construction and BIM are independent and separate, there are synergies between them that extend beyond the maturity of their contemporary approaches. However, their simultaneous adoption on the state of the art of construction practices is a potential source of confusion when it comes to assessing their impacts and efficiency. Lean Construction is a conceptual approach for projects management, while BIM is a transformational information technology (Sacks et al., 2010). In the same way, Dave et al. (2015) observed the synergic potential of Lean Construction and BIM throughout the whole life cycle of a construction project. Even though these synergies were studied in implementations of individual designs, there is no systematic exploration strategy, and there is a lack of integration technologies capable of concretizing these synergies.

Hosseini et al. (2018) states that to augment Facility Management (FM) performance towards business growth and prosperity it is crucial to convert a building's in-use data and information into tangible business knowledge. However, as pointed by Carbonari et al. (2018), there are still several barriers that limit the uptake of BIM for FM, such as knowledge, software compatibility, data ownership, reliability of information, and without a structured approach for looking at existing buildings, the number of facilities managers using BIM will always be limited to the those who manage new buildings. In this context, Lean principles can be applyed to the FM to identify the value added and non- value added activities in the process (Sharma et al. 2007). Lean can improve the FM processes by identifing actual value creation process between the input and output and providing tools for managing the value creation, but the leaner value creation practices need to be aligned with the new way of thinking in order to remove the waste activities of the facility management (Jylhä and Junnila, 2013). Therefore, LP principles and BIM functionalities can be combined to provide tools for managing the value creation challenges, supporting and improving the FM service process.

2.9 Lean Production and Six Sigma

According to Maleyeff et al. (2012), LP has its roots on the Toyota Production System, which began in the 1950s and aimed to reduce waste through an extensive employee involvement, and healthy relationship with suppliers and customers at problem-solving activities. For Aziz and Hafes (2013), LP comprises two pillars: (i) JIT flow, which consists of producing according to demand; and (ii) Jidoka, which consists of man-machine separation, in which an operator manages multiple machines. However, Taj and Morosan (2011) affirm that LP is a multidimensional approach based on the following practices: JIT, cellular layout, total preventive maintenance, total quality and human resources management. For Chaurasia et al. (2016), the factors that characterize a lean environment are: reduced delivery times, accelerated time to market, reduced operating costs, exceeded customer expectations, streamlined outsourcing processes, improved visibility of business performance and use of more productive forms of energy, equipment and people.

Currently, LP represents a mind-set and must be adopted by employees at all organizational levels in order to produce truly sustainable results (Voehl et al., 2010). According to Chaurasia et al. (2016), "LP is an endless journey to reach the most innovative, effective and efficient way in an organization." For Voehl et al. (2010), organizations that seek LP implementation, should have the following characteristics: focus on business; training of managers; support for employees; customer orientation; sharing success; analyze opportunities for improvement; real multifunctional teams; sense of community; customer-focused processes; flexible equipment's; quick tool change over; learning environment; alliance with suppliers; information sharing; analysis of activities that add value; thorough knowledge of the process; problem prevention; organization, cooperation and simplicity. LP thus provides a means to do more with less - less human effort, less equipment, less space and material – while providing what customers want and value (Mathaisel, 2006). According to Sacks et al. (2010), there are sixteen lean principles:

1. Variability reduction;
2. Decrease of number of cycles;
3. Reduction of sample size;
4. Flexibility increase;
5. Selection of an appropriate method of production control;
6. Standardization;
7. Institution continuous improvement;
8. Visual management use;
9. Production system design for value chain flow;
10. Ensure comprehensive requirements capture;
11. Focus on the concept selection;
12. Guarantee operating flow requirements;
13. Verification and validation;
14. Go and see for yourself (Gemba);
15. Decision by consensus, considering all options;
16. Cultivation of an extensive network of partners.

With regards to Six Sigma approach, created by Bill Smith at the Motorola Corporation in the 1980s, it seeks to reduce variability in order to reduce errors and defects by applying the DMAIC cycle (Maleyeff et al., 2012). Popa et al. (2005) argue that Six Sigma is a highly disciplined process that helps organizations focus on delivering lower cost products with improved quality and reduced cycle time. The term "Sigma" represents a statistical measure that verifies the extent to which a given process deviates from perfection. According to Franchetti (2015), Six Sigma can help developing skills, improving knowledge and employees' morale and the ability to use a wide range of tools and techniques. In addition, it has the following advantages over total quality management: setting zero defaults targets and intensive use of statistics, data to make managerial decisions and reduce process variation.

Factor	Lean Production	Six *Sigma*
Origin	JIT	Total Quality Management (TQM)
Theory	Eliminate waste and improve processes	Reduce variability
Focused Area	Flow of value	Problem solving
Key factor	Reducing waste without added value improves process flow	Reducing variability reduces the problem
Primary Key Benefit	Reduces lead time	Standardizes and controls process output
Secondary key benefit	Reduces waste Uniform output Inventory control Flow Matrix Improves quality Reactive issues "empowered"	Reduces variability Improves the first processing time Inventory control Matrix of variability Quality rate is high Reactive issues "empowered"
Drawbacks	Less concentrated in statistical process control tools	Process system is not considered; Improves independently and has no standard solution to common problem and its failure will affect the entire chain
Key Tools	Value Stream Analysis Error protection or poka-yoke Takt time or pull schedule based on customer demand Kaizen-blitz Visual control 5S Standardized work Kanbans - JIT delivery One–Piece Flow Smed or quick tool change Total productive maintenance Overall Equipment Efficiency (OEE) Heijunka Jidoka Yokoten	Process Mapping / Process Flow Cause and effect diagrams Supplier-input-process-output-customer diagrams Pareto Charts Histograms-distribution analysis Statistical Process Control Regression analysis - scatter plots; Variation analysis Hypothesis test Root Cause Failure Analysis Fault mode and effect analysis 7 quality tools Lean Tools
Key instrument	Kaizen event	DMAIC

Table 1. Differences between Lean and Six Sigma

Source: Adapted from Chaurasia et al. (2016)

The main difference between LP and Six Sigma is that lean projects can use qualitative and quantitative analysis of root causes, such as the five whys, cause and effect diagrams, mode analysis and failure effects (FMEA) (Voehl et al., 2010). However, by focusing on process improvement and reduced variability, Six Sigma does not guarantee a sustainable competitive advantage, and it is necessary to develop mechanisms that address product innovation, the pattern of change in the customer base and environmental uncertainty. At the same time, it improves organizational processes, considering radical changes and the formation of new markets and/or customers (Parast, 2011).

George (2002) states that integrating both approaches to reduce cost and complexity is essential. Just as LP cannot statistically control a process, Six Sigma alone cannot dramatically improve process speed or reduce invested capital (George, 2003). Six Sigma helps to connect business leaders and key project teams in a potent two-way fact-based dialogue, which is considered a blind spot to LP. For Voehl et al. (2010), in the appropriate situation, both approaches to process improvement can be integrated to form a more comprehensive methodology regardless of size or scope, and root cause analysis is the common cross-point between these approaches.

2.10 Lean Six Sigma

Lean Six Sigma (LSS) "is a methodology that maximizes shareholder value by achieving the fastest rate or bringing improvements in customer satisfaction, cost, quality, process speed and invested capital" (George, 2002). It is a holistic methodology that is based on systems approach and considers the entire supply chain (Franchetti, 2015). LSS is a process improvement methodology used by organizations of international recognition to eliminate waste in processes and deliver products and services with extreme quality to their customers (Popa et al., 2005).The intense pressure for the efficient utilization of resources has generated a global expansion of knowledge with respect to LSS methodology in the oil and gas sector. Such dissemination has been guided through training and specialized programs with employees (Bufalo et al., 2015). Recently, there are promising cases that show the adequacy of the LSS methodology also in the energy sector. Alqahtani and Nour Eldin (2011), for instance, conducted in Saudi Arabia an energy assessment study following the LSS methodology to identify, quantify and classify, technically and economically, possible energy conservation opportunities in an oil and gas separated plant by Saudi Aramco. In addition, LSS methodology has expanded the seven original wastes Ohno (1997) and recognized nine forms of waste - defects, overproduction, transport, waiting, inventory, movement, over processing, underutilized employees and behaviour - showing more emphasis on waste reduction than reduction of variability (Voehl et al., 2010).

Thus, LSS seeks to eliminate these wastes and provides goods and services at a rate of 3.4 defects per million opportunities (DPMO). According to George (2003), LSS incorporates the principles of speed and immediate action of LP with the defect-free vision from Six Sigma with a reduced variation in the queue time. From this, LSS attacks the hidden costs of complexity and is a mechanism that seeks the engagement of all employees for improving quality, lead time and cost. Therefore, it is verified in the literature that some empirical studies use the LSS in the context of Oil and Gas in Supply Chain (AL-Riyami et al., 2017), Operations (Buell & Turnipseed, 2003; Buell & Turnipseed, 2004; Bubshait & Al-Dosary, 2014; Mustapha, Umeh & Adepoju, 2015), and Engineering, Procurement, and Construction (EPC) projects (Villanueva & Kovach, 2013). However, this research in the literature makes clear the lack of works that proposes practical guides for the implantation of LSS sector with training of the stakeholders for sustainable Lean Journey in different contexts of the Oil and Gas.

2.11 Value Stream Mapping (VSM)

A successful LP implementation depends on a series of practices and principles that have a high degree of interdependence and synergy (Fahmi and Hollingworth, 2012). The lack of understanding of this systemic characteristic by the top management leads to failures in adopting LP, since there may be a belief that with a partial implementation a large part of the benefits can be obtained (Shah and Ward, 2003). In this sense, a value stream involves any activity necessary to transform the raw material into finished product (Rother and Shook, 1999). Hence, VSM allows mapping both the flow of materials and information that supports the production (Braglia et al., 2006), evidencing the existing opportunities (Tyagi et al., 2015).

By applying VSM, it is possible to avoid carrying out random improvement initiatives that do not bring solid results to the bottom line (Sim and Rogers, 2009). VSM provides structured continuous improvement that leads into a lean value stream and entails a continuous improvement culture within the organization (Stone, 2012). Further, VSM enables the creation of a shared perspective of both the current issues and the future vision for the value stream, trespassing departments' limits and providing a horizontal improvement of processes (Seth and Gupta, 2005; Taylor et al., 2013).

It is worth noticing that, according to Lian and Van Landeghem (2007) and Dal Forno et al. (2014), the implementation of the improvements indicated from the VSM may not always provide the expected benefits, and differentiating the actual value stream from the envisioned one. LP implementation in a traditional manufacturing company raises a number of possible changes, such as human resources management, plant layout, flow of information and goods, and production planning and control (Detty and Yingling, 2000; Marodin and Saurin, 2013).

Hence, the potential implications of the addressed issues in such a variety of factors may hinder LP acceptance and deviate improvements from its original plan, changing the implementation approach and its benefits (Abdulmalek and Rajgopal, 2007). However, Spear

(2009) and Bhamu and Sangwan (2014) emphasize that a truly LP implementation relies on a widely disseminated continuous improvement experimentation guided by a scientific method that supports the understanding and learning of employees from all levels. Therefore, it is reasonable that not all improvements raised from the VSM provide the expected outcomes when implemented, but the benefits of the learning process will be established independently of that and feedback further future states (Bhasin and Burcher, 2006).

Despite evidenced in several kinds of companies and sectors, practitioners should be aware of some important contextual distinctions when applying VSM (Wojtys et al., 2009; Doğan and Unutulmaz, 2014; Collins et al., 2014). One important contextual condition to be acknowledged is the existence of high process variability. In this situation, the solution usually employed is to use the lowest and highest values in order to find the scenarios of worst and best case in the estimation of the lead time of the value stream (Braglia et al., 2006; Tegner et al., 2016). To address such issue, previous studies have suggested the integration of other techniques into VSM in order to complement its approach. For instance, Seyedhosseini and Ebrahimi-Taleghani (2015) combined VSM with the concept of cost-time profile and analyzed both cost and time variabilities through stochastic models. Braglia et al. (2009) incorporated fuzzy logic and probabilistic methods into VSM to approach processes variabilities. Woehrle and Abou-Shady (2010) added simulation models to VSM in order to verify the financial uncertainties related to the LP implementation.

3 MATERIALS AND METHODS

The research methodology of this doctoral thesis explores a qualitative and quantitative approach, since it combines new technologies, socio-technical methodologies and static analysis of data (Yin, 1999; Voss, 2010; Gray, 2012). The individual articles complement each other in favor of an integrated sustainable supply chain, aiming to meet real demands of society dynamically through the digital recycling factory. Figure 3 details the scientific methodology of each article in a complementary way in favor of the factory 4.0.

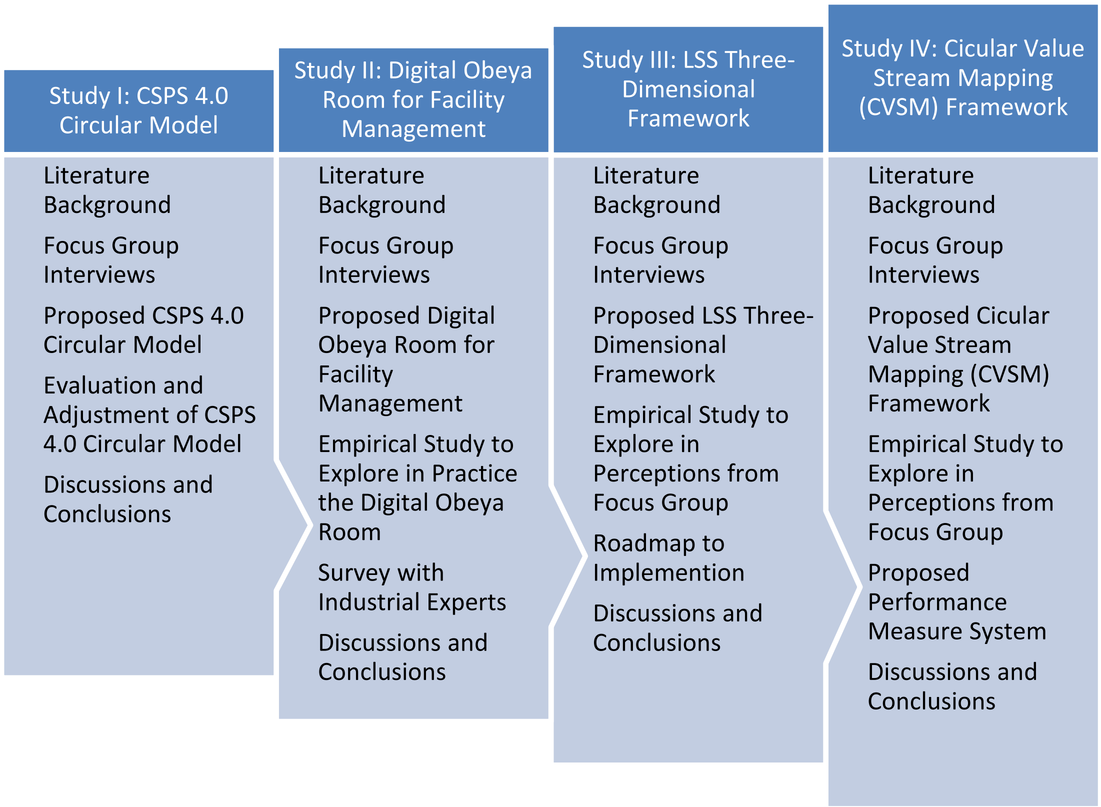


Figure 3. Perspective of Thesis Articles

The first article concerns the proposal of a digital recycling factory that needs to understand the exact specification of the discarded components of the oil and gas industry, explored by the second article that proposes with empirical evidence of application a synergic model between BIM and Lean for the facility management, allowing the monitoring of components close to the disposal of an industrial plant. The third article proposes a model for operations management that allows to improve the operational efficiency and to predict the monitoring of components that need repairs or substation of the asset. Finaly, the four article consider these three articles to propose the CVSM framework for circular economy implementation in the oil and gas sector.

3.1 Study I

3.1.1 Study design and research steps

Through the best combination of additive manufacturing, smart production systems, circular economy and sustainable supply chain management from literature background, this article proposes an innovative framework for circular waste recycling. Thus, the next step is to analyze on Figure 4, to improve and collect specialist's perceptions by Focus Group Interviews(FGIs).

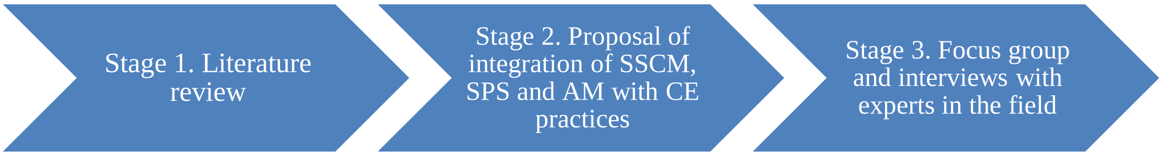


Figure 4. Research Steps on CSPS Model

From the establishment of the central question of the research, the following steps are performed:

- Literature Review: presenting the current practices on Transition towards Circular Economy, Sustainable Supply Chain Management, Smart Production Systems, and Additive manufacturing;
- Proposed CSPS model: exploring the concepts presented in the review section of the literature, as well as describing the steps to re-manufacture e-waste and recycle scrap using 3D printing;
- Discussions and Conclusions: FGIs to assess the theoretical and practical implications of the CSPS model, as well as to report points of attention and incremental improvements.

The approach assumed in this work is exploratory in nature because it aims at bringing together the most relevant information available in the literature. It is also descriptive because it seeks to reveal how information can be presented to society for circular economy purposes, and how to replicate these methodologies and technologies in similar environments. As a research strategy, according to Voss et al. (2010) and Childe (2011), two approaches were used: exploration, and theory-building.

3.1.2 Data Collection

3.1.2.1 Literature review

A literature review was deployed to locate relevant studies and to evaluate their respective contributions and then formulate RQs. Electronic databases (EDs), including Elsevier (sciencedirect.com), Scopus (scopus.com), and Springer (springerlink.com), were used. The research used classifications for the nature of the objectives, including exploratory and descriptive inductive logic, with data collection from primary and secondary sources using a qualitative approach. In relation to the results, the methodology represented applied research, using the literature to map emerging issues related to Industry 4.0, AM, and CE. For the search of literature, we used *'CE' AND 'SSCM' OR 'Industry 4.0' OR 'AM'* as a keyword string.

The review consisted of four stages: (1) formulation of the central RQs; (2) selection and evaluation of studies; (3) content analysis of selected articles; and (4) description of the results. The literature review steps and the selection results are presented in Figure 5. The first step was to determine the barriers, challenges, and obstacles to CE implementation and to examine how it would be possible to monitor or measure their operationalisation through Industry 4.0. In the second step, we conducted the search, considering only scientific papers from journals and reviews related to the environmental and social sciences, engineering, or management that were available in English. In the third step, only titles primarily related to the topics of CE and Industry 4.0 were considered, and the authors reviewed the summaries and read the articles of all relevant texts, adhering to the themes mentioned above.

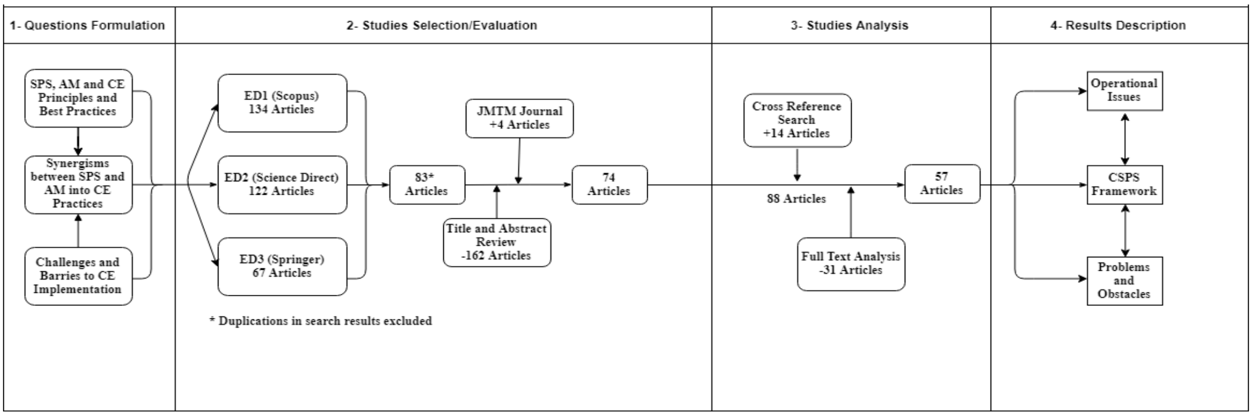


Figure 5. Literature Review Steps

3.1.2.2 FGIs to Analyze the Perceptions of Public of Interest

For the focus group conducted in the next stage, four discussion rounds were conducted from September 2017 to November 2017 with 19 experts (six mechanical engineers, eight professors of operations management, two automation engineers, and three production engineers) who are specialists in 3D printing and materials engineering. A focus group is a qualitative research method encapsulating principles of stakeholder analysis in a qualitative manner for the accentuation and incorporation of preferences in the decision-making process. The FGIs were aimed at discussing potential improvements in scrap metal, polymer, and/or electronic waste management in order to raise the added value of existing wastes for creation of a proposed CE model. At the end, a 'lesson learned' workshop was held with all specialists to propose improvements and to debate the scientific and practical contributions of this process. Initially, a seminar was held for the stakeholders where the presentation opened with an explanation of the study's context and aims, including the stages of the proposed model to achieve triple bottom line results. General information was shared about the respondents and their organisations (e.g. type of institution, name of respondent's department, and his or her position along with their professional experience. Next, the following four sessions were conducted for data collection:

(1) An overview of the proposed model, intended to share basic knowledge among participants.
(2) Brainstorming with stakeholders about challenges and lessons learned for deployment of the proposed model, discussing facts, data, and mechanisms for implementation.
(3) Zoom and filter session presenting the proposed model and evaluating theoretical and practical implications, including outcomes in environmental, social-technical, and economic dimensions.
(4) Details on demand session, which was a description of the workflow of CE logistics, AM, and CSPS for replication in future studies.

After the above, an evaluation was completed that consisted of the two stages of interviews focusing on explicit information in the RQs and conducting four FGI sessions to discuss a topic raised by a skilled moderator. As in Mishra et al. (2016), our FGIs were carried out by two researchers, where one researcher facilitated the content and process of the FGI by assisting the participants, and the other recorded the discussion, with prior permission of participants, and subsequently created the transcripts. The duration of each focus group interview was about 60 to 90 minutes. An overview of the moderation guide for focus group discussion is as follows:

Introductory questions:

- From your perspective, please describe how you define circular manufacturing.
- How important is circular manufacturing for your company when compared with other competitive manufacturing capabilities?

Main questions:

- Based on your experience, what core capabilities are required in manufacturing processes, systems, supply chains, services, managerial practices, and/or technologies to enable a transition from linear to circular manufacturing business models? And how can these be developed?

- What are the challenges to implementing circular business models? And what are the key benefits?
- How do SSCs provide support for circular manufacturing? What form of advance manufacturing technology does your organisation employ?
- How do Industry 4.0 technologies contribute to enabling the circular capability of manufacturing processes and systems?
- Please explain the importance of smart production systems and AM in providing a circular economy in your organisation.

Closing question:

- We want to explore possible lessons learned from circular manufacturing implementation. Is there anything you want to add apart from what we have already talked about?

The opening questions gave participants the chance to become acquainted and feel bonded. For that reason, the questions were constructed so that people could feel confident as the talks progressed, while also identifying common characteristics of the participants. The facilitator functioned as the key person in the four discussion rounds and had the responsibility of coordinating the discussions, while the other researcher was responsible for the recording and taping of the four discussion rounds.

3.1.3 Data Analysis

The abductive data analysis, based on qualitative coding, related to the interpretation and contextualisation of a phenomenon within a conceptual framework (Lewins and Silver, 2007; Nascimento et al. 2017). Finally, the transcripts of the interviews were analysed using open coding to capture any emerging concepts (Strauss and Corbin, 1998; Caiado et al. 2018). In the second phase of the analysis, the data was coded more systematically into theoretical categories which were used to construct the model. In addition, the results of the focus groups and meetings between the authors of this work generated an understanding of the steps and requirements necessary for the proposed model. A critical analysis of the implications of the proposed model for theory and practice was carried out, generating a triangulation between literature, focus groups, and empirical study to create a circular economy model taking into consideration the concepts of Industry 4.0. Therefore, the data analysis was based on the triangulation to generate knowledge through a conceptual framework that detailed the ways to implement CE with the technologies of Industry 4.0 and the challenges to that implementation.

3.2 Study II

3.2.1 Research Method

This paper is based on an exploratory approach, aiming to bring up significant information of Building Information Modeling tools and Lean principles regarding implementation in construction projects, in order to identify the applicability level of visual management in PDCA cycle. In addition, it can be classified as descriptive due to the aim to disclose a manner to present information, showing its reflexes on related environments. To consolidate the methodology, a case study method using the Digital Obeya Room was completed, including its application in a real project and comparison and discussion of this analysis with the results of a survey applied to specialists in order to assess the relevance of each BIM-Lean principles for facility management. The research study applied a triangulated methodology with qualitative and quantitative data collection mechanisms. The data was gathered using three methodologies:

(5) Literature review on the related works of BIM-Lean approaches, through an intuitive and inductive way;

(6) Empirical investigation is carried out in an industrial plant facility to evaluate the BIM methodologies and technologies for the preventive maintenance planning and control; and

(7) Application of a survey questionnaire with managers, researches and BIM specialists to assess the relevance of each of the BIM-Lean principles for the construction industry.

It may be observed that the research counts on multiple sources of information and iteration with the constructs developed from the literature, which enables further constructive validity (Eisenhardt 1989). To Miguel (2005), the use of multiple sources allow for the support of the constructs, propositions and hypotheses, in other words, the technical use of triangulation helps in the iteration and convergence between various sources of evidence. The empirical study was considered acceptable as the data are gathered from diverse procedures, avoiding the subjectivity of the researcher and guaranteeing the quality of the results (Yin 2005); and increasing the precision of empirical research (Runeson, Höst 2009).

3.2.2 Survey design, sampling and data analysis

Next, a survey was fullfill to measure the implications of BIM-Lean approaches, according to the perception of professionals that working in the oil and gas sector. Survey design was informed by discussion with a research specialist and a preliminary review of the literature. A pilot survey questionnaire was answered by four professionals, two collaborators who were knowledge on BIM concepts, including a manager involved in the case study and an engineer from a construction company. Thus, the revised questionnaire offers a better refinement of the questions, ensuring that experts, professionals and academics would have no difficulty in answering the questions. In order to organize the questionnaire in a logical sequence and to better understand the subject studied, the questionnaire is divided into two areas. The first area determines the demographic details of the specialists, such as gender, age, education degree and years of experience with BIM. The second area focussed on analyze the degree of relevance of each BIM-Lean principle. All responses on the relevance of guidelines items were recorded using a five point Likert scale (1 – "very applicable" to 5 – "very applicable").

An electronic questionnaire is developed for data collection in "Google forms" (https://docs.google.com/forms). The length of time to answer the questionnaire was about 15 minutes. In November 2016, the web-based surveys were distributed via email to twenty managers currently active in the construction industry, eighteen researchers and twenty-six BIM operators/experts. Therefore, the intended population of this study consists of 64 professionals who are users of BIM technologies and practitioners of Lean techniquesSampling for convenience is done (Sekaran, Bougie 2010), since this study aims to investigate the most applicable variables (Calder et al., 1981). The period of application of the research was approximately five months, ending in March, 2017. A total of 41 questionnaires were collected and after the manual screened check of the data, ignoring those with incomplete questions, this resulted in 32 valid questionnaires. As Hines and Montgomery (1990) and Sureeyatanapas et al. (2015) in small populations, a questionnaire with a sample of at least 30 respondents allows a acceptable descriptive statistic. Descriptive statistics were used, including frequencies, percentages and mode, to describe sample characteristics analyzed. Table 2 details the respondents' profile.

	Number	Percentage
Sex		
Male	24	75%
Female	8	25%
Age group		
18-30	16	50%
31 – 50	12	37%
> 50	4	13%
Education degree		
Undergraduate	3	9%
Graduate	7	22%
Postgraduate	6	19%
Master	9	28%
Doctor	7	22%
Years of experience		
None	4	12 %
Less than a year	3	8 %
One to three years	4	12 %
Four to six years	6	20 %
Seven to ten years	3	8 %
More than ten years	13	40 %
Job/Function		
Manager	13	41%
Researcher	7	22%
BIM operator/expert	12	38%

Table 2. Characteristics of Study Respondents

The professionals interviewed are predominantly managers, accounting for 41% of the total. Following by 38% of BIM operators/experts. The majority of interviewees are between 18 and 30 years old (50%), and 40% of respondents have more than ten years of experience. In addition, around 50% of interviewees have at least a master's degree, which shows a high level of academic formation. Thus, the sample was considered adequate for the research.

3.3 Study III

3.3.1 Research Method

The proposed method in Figure 6 is eminently exploratory and is comprised by three steps. The first step presents a literature review of the concepts and critical success factors related to LSS, taking into account the principles and convergences between LP and Six Sigma. In the second step an empirical study is carried out in an oil and gas company to evaluate the synergism between LP principles related to PDCA and DMAIC cycles. This assessment was undertaken through the establishment of focus groups with company's collaborators, who are responsible for cost reduction and continuous improvement. The protocol of the empirical study was based on existing methodology of focus group literature (Blindheim, 2015; Nascimento et al. 2017).

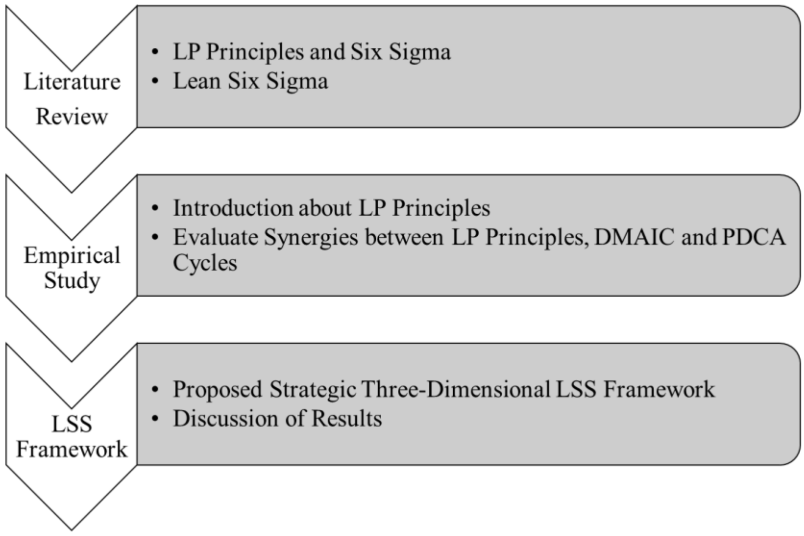


Figure 6. Research Steps to Propose Strategic LSS Framework

The adopted procedure analyzes the Strategic Three-Dimensional LSS Framework through the perception of collaborators of the oil and gas industry, as well as LSS specialists. The approach was chosen because the respondents confirmed their understanding of the proposed framework, arguing for consensus to generate comments for continuous and incremental improvement of the construct. The events stimulate the participants to challenge, disagree, and agree with different points of view of each one's perspective, if necessary, to modify the framework and generate a consensual version via focus group (Blindheim, 2015). Finally, the third step presents the consolidation and analysis of the previous step outcomes, enabling the proposition of a framework that integrates and supports a synergistic approach between LP principles, Six Sigma (DMAIC) and Kaizen (under PDCA) to implementation in the oil and gas sector.

3.3.2 Data Collection

In this paper was conducted an inductive and intuitive narrative literature review in order to locate relevant existing studies based on prior formulated research questions, to evaluate and synthesize their respective contributions. To analyze gaps in the current practices and related works of literature background. This review consists of consecutive steps: (1) formulation of the questions and search string with main keywords, (2) location of studies, (3) evaluation and selection of studies, (4) analysis and synthesis, and (5) reporting and use of the results (Garza-Reyes, 2015; Saieg et al. 2018). Identifying the main keywords is extremely critical to a comprehensive and unbiased review. The search is limited to a set of keywords, the search strings used were:

- Theoretical search string: ((('Lean' AND ('Production' OR 'Manufacturing' OR 'Operation*' OR 'Thinking') AND ('Six Sigma')) OR ('Lean' OR 'Lean Six Sigma' OR 'LSS')) AND ('Oil and Gas')
- Methodological search string: ('Focus Group' OR 'Interview*') AND ('Production' OR 'Planning' OR 'Control')

The search of these keywords was made in the following databases: Scopus, Emerald, Taylor and Francis, IEEE Xplore and Wiley Publication. The conducted research had combined the search terms into title, abstract or keywords, limited to papers published in peer-reviewed journals up to May 2018, when they were available. In the analysis of design for the refining, exploration and production of petroleum, serial interviews were conducted in September of 2016 through workshops discussions for the collection, treatment and presentation of the main problems, identification of the causes and effects perceived (Tortorella et al., 2008). The focus group discussions were held on a regular basis between October 2016 and March 2017 and in parallel with the literature background analyzed, complementing with a proposed framework that provide a guide to implement LSS in the oil and gas sector. Besides permit that these methodological approaches can occur in different contexts to adjust the interactions between LP, PDCA and Six Sigma (DMAIC) in some specific area.

The number of participants in each discussion ranged from 5 to 9 in relation to the response rate of each event. A total of 12 collaborators, who were responsible for leadership activities, were assigned to two groups. In this context, the criterion of selection of the focus group sample is presented: (i) objective: analyze LP and Six Sigma in order to develop a framework that combines the principles of LP, PDCA with Six Sigma (DMAIC) via focal groups and discuss their implications for theory and practice; (ii) reference units: processes, materials, technologies and people; (iii) informing unit: managers, coordinators, consultants and engineers that working in the oil and gas; (iv) unit of analysis: tree-dimensional LSS framework in the oil and gas context; (v) sample unit: people who had greater knowledge on the central theme of the investigation and held leadership positions. The groups were carried out through collaborators who have had some experience or previous study on LP, considering five years of minimum experience.

In the interviews, recordings and annotations were made, as well as modifications on the proposed model to implement LSS and transcription of the results through tables, graphs and diagrams. Each focus group discussion took about an hour and a half. Participants were confronted with a list of lean principles described and sent earlier. This list (accompanied by a meaningful explanation from the moderator) was presented at the initial workshop as input to the focus group discussion. The central question was: which Lean principles are preferentially applicable at each stage of PDCA cycle in the DMAIC for guide an LSS implementation?

3.3.3 Focus Group Design and Data Analysis

The instrument for validation of tri-dimensional LSS framework was focus group, with the aim of ensuring an analysis of context, organizations culture and human factors to achieve continuous improvement process, as follows below:

- Introductory opening for the recipients, including the purpose of this study;
- General information about the respondents—ask respondents to provide general information about them and their organizations, e.g., type of industry, name of respondent's department and his/her position, as well as the number of years of experience the respondent has in the organization;
- Four sections for data collection.

These included:

- Section 1: overview first of LP and Six Sigma—intended to find out the respondent's basic knowledge on these tools and principles of Lean practices;
- Section 2: zoom and filter within the DMAIC and PDCA Cycles—to examine the respondent's knowledge about LSS;
- Section 3: details on demand of alignments or misalignments between LP, DMAIC and PDCA Cycles — to evaluation and measure the extent of knowledge that respondents have about boolean linkage LP principles to DMAIC and PDCA cycles;
- Section 4: discussion of literature background, empirical investigation and focus group interviews to collect the perceptions of three-dimensional LSS framework in the oil and gas context to find out respondents' opinions.

In addition, in this focus group, one of the authors of this article was the technical moderator (introducing issues, structuring the discussion) and another author fled as an annotated assistant (Lans et al., 2014). The results of the two discussion rounds follow the protocol of the Focus Group technique (Xenarios and Tziritis, 2007). The study is considered valid insofar as the data are obtained from different procedures (literature, documents, focus group rounds and experiments), which constitutes a triangulation, avoiding the subjectivity of the researcher and guaranteeing the quality of the results (Greenhalgh and Taylor, 1997; Voss, 2002; Yin, 2013).

3.4 Study IV

3.4.1 Research Method

The methodology of the present investigation uses multiple primary data collection procedures that configure a triangulation between literature, documents and focus groups. The constructivist theory is applied to the proposition of the Circular Value Stream Mapping (CVSM) model with empirical validations through focused groups to evaluate the proposed construct. Thus, the following sections present sample selection and collection mechanisms, as well as analysis of the data obtained.

3.4.2 Sample selection, focus group interviews and data collection

The sample selection criteria are established as follows: (i) Critical Review of CE and VSM current practices; (ii) Constructivist Theory Approach to create the CVSM model; and (iii) Focus Group Interviews to discuss the empirical constructivist results. The selected research databases are Scopus, Engineering Village, Science Direct and Google Scholar, using keywords inherent to VSM, CE, Lean Systems and Sustainable Management Systems. From the results presented by the critical review, serial meetings are held between the authors of the present work for the construction and proposition of the CVSM model, since it was verified in the existing models of the literature the need to create lean productive systems for sustainable production of municipal waste. Thus, from the first conceived version of the CVSM model, relevant researchers were selected in these respective areas to evaluate the proposed construct. The focus group participants' characterization highlights their respective areas of activity, being presented by the description of the four participants present at events with more than ten years of experience: (i) Professor in Sustainable Management Systems at Derby University; (ii) Professor at Lean Systems at Federal University of Santa Catarina; (iii) Professor in Sustainable Management Systems at Federal Fluminense University; and (iv) Researcher in Sustainable Management Systems at Tecgraf Institute of PUC-Rio.

3.4.3 Data Analysis

Data analysis is performed with three stages, characterizing a qualitative and quantitative triangulation according to Gray (2010): (i) in the first stage a classification and segmentation of current practices in the VSM and CE literature is performed. in favor of sustainable management systems, convergence and divergence analysis through spreadsheet that categorizes barriers, benefits, research methods, results and keywords by selected article;

(ii) in the second stage, a consistency analysis of the literature data is conducted that directs the creation of the VSM circular conceptual model (CVSM), considering the creation of new metrics and indicators inherent to the traditional VSM for the analysis of unambiguous routes, rhythm and routines. moving a technology recycling center in line with industry 4.0 principles; and (iii) analysis of the results for discussion and verification of opportunities for improvements in the CVSM model, considering adjustments for the continuous and incremental improvement of the production processes inherent to the digital urban waste recycling plant. Above all, there is a triangulation between document data, literature and tacit knowledge from discussions through focused groups, considering experienced participants that allow objective local conclusions that can be customized in the proposed CVSM model according to different possible contexts for recycling. of municipal construction waste.

3.5 Synergisms between Studies to Achieve Interdisciplinarity

Since the methodologies related to each article published and submitted are presented in the previous subsections, there is a need to unify methodologies in an integrative perspective that explores convergent concepts in favor of interdisciplinarity in sustainable management systems. Thus, a methodological process is performed in Figure 7 that each article presented explores in its essence, considering from the identification of the problem

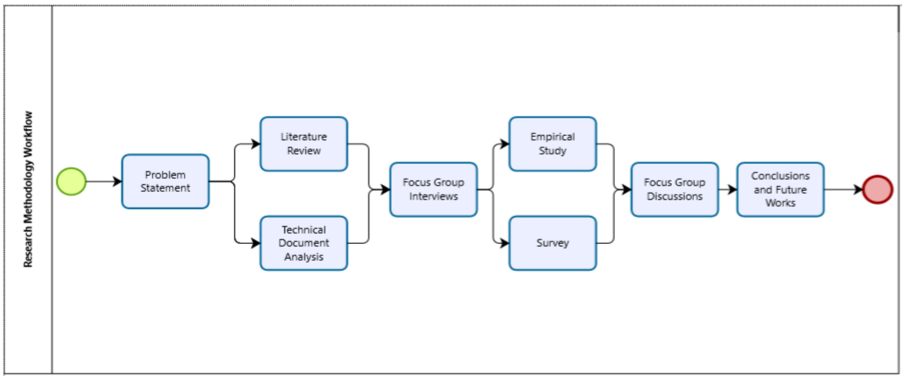


Figure 7. Research Methodology Worflow for Each Publiched Article

situation to FGI's for discussions in favor of interdisciplinary conclusions.

The process begins with the definition of the problem statement that guides each investigation, generating central and secondary questions for literary and documentary analysis of the state of the art for problem-solving. Thus, social iterations stand out for the qualitative assessment of the causal link and the definition of interdisciplinary countermeasures, considering the generation of guidelines and goals for each research (article). To evaluate in practice the perception of the public of interest of each model, an empirical study with the industry sector is carried out through the application of technologies and methodologies with the evaluation of standardized questionnaires. The results of the empirical assessment of the generated constructs are validated through FGIs for discussion, generating advantages and disadvantages, convergences, and divergences, as well as standards and lessons learned for CE practices deployment in the oil and gas sector.

4 RESULTS

4.1 Study I

4.1.1 Overview of Circular Model

According to an alarming societal need, various initiatives in the manufacturing industry are expected to diminish the negative impacts on nature caused by the growing of economies worldwide. In this context, a model has been developed, for waste reutilization in the case of solid non-organic materials, available in the urban or industrial medium. In the Figure 8, one can generally observe the proposed chain of processes, all of which can be grouped in seven different phases of a circular structure. Each phase or step is intimately associated with the reverse logistics of materials.

Figure 8. Circular Model for Reuse of Waste

As can be seen in Figure 8, it is proposed a chain of processes, which, in general, can be grouped into seven different phases of a circular process. Each step from the reverse logistics of junk is presented in the following items:

- Product Lifecycle: This phase simply represents consumption or operation in the life cycle of a product. For this model in question, this product may be any manufactured product used in the domestic or industrial environment provided it is a solid residue, for example a blender, a television, cellular apparatus, a microwave apparatus, a table, backyard chairs , as well as scrap from industrial wastes;
- Selective Waste Collection: It represents the collection of the products mentioned in the previous step by cate- gory of products, after the products' life cycle has been finished for any reasons, such as their bad or no longer functioning, their obsolescence with new products available in the market or simply their rejection by part of the user. The strategy for an intelligent collection is detailed later in this paper;
- Waste Sorting: In the stage of separation of the materials present in the collected products as already happens now several steps of this process in modern centers of separation for recycling. Therefore, at this time, metallic and plastic materials, wood, glass or any other type are grouped into categories and subcategories in an organized way and in the most efficient possible way , so that they can be used in the next stage of the cycle;
- Waste Treatment: This step is one of the great challenges of the model. Here, each type of material must go through specific physical or chemical processes that transform the separated material into input for already developed 3D printers. The transformation of the separate material into input for 3D printers is a critical success factor for future recycling and will allow the fabrication of entirely new and sophisticated products from the old commodities;
- Product Printing: This phase represents all the 3D printing processes performed with the inputs from the previous step. By exploring 3D CAD/CAE tools and Digital Twin concepts in the designs associated with printers, it is possible to print products of varying sizes and design, from simple decoration articles to complex geometry mechanical components for industrial purposes. Products that are already able to fulfill their purposes immediately after the printing process go directly to the Product Selling stage. On the other hand, if

the printed product is only one component of a more complex final product, the printed product proceeds to the product assembly step;

- Product Assembly: This step refers to the assembly phase of a final product demanded based on the components made available by the 3D printers, which may have been printed each with different materials. For example, assembling a blender would require 3D printing with metals for one of its components at least - the propeller and 3D printing with plastic materials for other components such as the liquid container and the base of the apparatus that protects the rotor and carries the buttons to control the appliance;
- Product Selling: This step, the sale of the product is carried out through the internet or in a physical store. At this point, therefore, the product made from recycled materials returns to the hands of the consumer to exert a new life cycle, thus closing the proposed cyclical model.

4.1.2 Zoom and Filter on Steps of CSPS Model

Thus, in this section of the work, each phase of the cycle is explained in more detail, as shown in Figure 7, except for Product Lifecycle and Product Selling, which may vary by product and sales techniques and, in general , only with the explanations given above are already sufficiently understood for the purposes of the model.

The innovation presented in this study is related to the CSPS model that mixes CE, SCM, AM and Industry 4.0 to the stages of Selective Waste Collection, Waste Sorting, Waste Treatment, Product Printing and Product Assembly, that is, all between the initial phase Product Lifecycle and the final phase Product Selling. In this context, a plan of action is described in stages, to obtain consensus via FGIs to implement a suistainable manufacturing model 4.0. Then the steps of the proposed model will be presented, according to Figure 9, reporting guidelines, barriers and rules for its application.

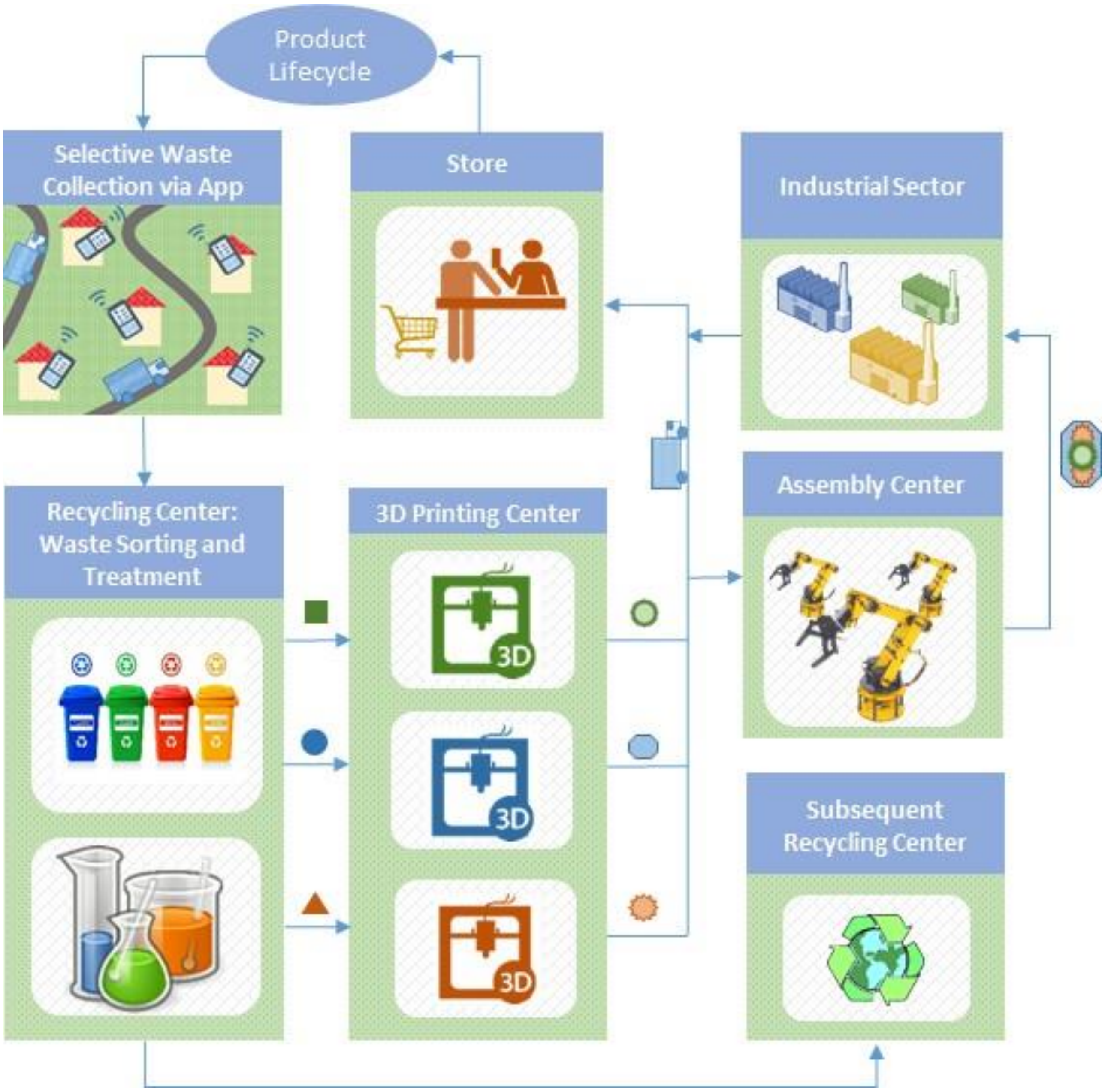


Figure 9. The CSPS 4.0 Model

The proposed selective collection phase involves two fundamental aspects: cloud computing and the transport system inspired by the milk run concept (a logistic model that allows the decentralization of waste collection by region and category of material). The use of cloud computing technology stems from the fact that, for a well-managed selective collection, it is necessary to have, besides the information on the location of the discarded products, as much data as possible on the types of materials that make up the products discarded at each location.

Thus, if there is a supply of, for example, a large amount of broken household appliances in one neighborhood and a large amount of old wooden furniture being dumped in another, the means of transport that perform the selective collection should be two distinct for each neighborhood and coherent with each volume of cargo offered. Not making sense is a pickup truck turning the neighborhood that does not offer the wood disposal. In the case, for example, of the first neighborhood offering a small amount of broken appliances, it is possible that the truck will be more efficient to get the appliances in this neighborhood only, nor will it need to run the neighborhood that only offers wood. The collection of the materials considering product categories makes the next step of separation of materials easier.

In order to be able to make this type of decision on the logistics of the collection, therefore, it is proposed to use a mobile application, in which the user registers the location of his residence or commercial establishment - any place where garbage / scrap is available for collecting - and chooses categories in which the garbage he has. Some possible categories of solid non-organic waste would be: kitchen electrical products, furniture, mostly plastic products, computer products and television sets. With this information provided through an application it is possible to have a map of the garbage offers in the city by category.

In this sense, with the help of software to optimize collection routes based on surveys on the streets of the city and the traffic conditions of these, moment to moment, it is possible to make a smart decision on what type of vehicle to send to the collection in each region and which optimized routes to follow. The concept of the milk run goes in this context as a strategy to make the cycle as a whole even more efficient. The milk run, in a simplified way, is a logistic system in which the delivery of one product and the collection of another in a given place are carried out with the same conveyor. With this system in mind, the following reasoning is proposed.

It can be seen from Figure 8 that the major transport activities occur in the selective collection and distribution stages for the customers of the products that leave the manufacturing center with 3D printers - in which case Sorting, Treatment, Printing and Assembly are close to each other. It is worth mentioning that a collection, manufacturing and supply structure that is dynamic and fluid is desired in the cyclic model presented, so it is aimed at minimizing the storage of products. This should be done by producing parts on demand from customers and therefore selectively collecting the raw material also according to the demand for manufactured products.

Thus, once the transportation of parts at the exit of the manufacturing on demand and the entry of raw material from the selective collection, it makes sense, within a same region of the city, that the transporters that deliver the products to customers, soon after, also carry out the collection of rejected products under categories. In this way, the milk run is applied to the cycle and its transport efficiency is increased.

With respect to the last proposals made, a last point should be considered: in the case that only one company is acting on this cyclical model, it is possible that the quantity of parts demanded does not counterbalance the quantity of rejected products offered. However, in the case of a multiplicity of companies working with this model, it is likely that there will never be rejected products in the residences or in any lots that are not of interest to any company.

4.1.3 Waste Sorting

The separation phase of the material gives rise to the selective collection and takes advantage of the fact that the materials already arrive separated by category. With the help of the application mentioned, which maps the volume and categories of garbage being produced and collected by the city, it is possible, even before the collection trucks arrive at the separation center, to obtain an estimate of which sectors of the center they will have to work more or less intensely. For example, if the garbage separation center basically works with human labor and there are only "broken household" items coming in, it is not necessary to concentrate employees in the area where the disassemble and separation of materials from the category occurs "furniture".

In addition, the arrival of products by category facilitates the efficient management of the unloading of collecting vehicles, since it allows to obtain, prior to their arrival in the yard of the separation center, a notion of the weight, volume and amount of cargo of which type it will need to be, soon, bustling around the courtyard. If the material separation and offloading activities are automated, which should occur in a real Industry 4.0 context, the data collected with the application also contribute to the efficiency of the separation center, since such data can be used by control algorithms of conveyor robots that move through the yard to move cargo, or of the automatic machinery that actually performs the separation of materials. The collected data can also be used for production simulation and cycle optimization purposes.

Within the separation center, each category of scrap requires its own separation methods for its components and materials. The separation methods for scrap can vary for each recycling company, but basically it must be dismantled for the separation of components, and these must be separated by types of material, such as: plastic, glass, wood and metal. These four materials, specifically, can now be used as components or feed-stock for 3D printing machine supplies.

Glass printing, however, is still a technology that is underdeveloped compared to printing techniques that make use of the other three types of materials. It is important to note that there are still a number of limitations as to how such materials should be used as input, since 3D printing technology is still taking its first steps. However, it is expected that the obstacles will become smaller as the decades advance, and that the use of this manufacturing knowledge and associated techniques will become ever more widespread.

4.1.4 Waste Treatment

The Waste Treatment phase is the most crucial step for the model cycle. It corresponds to the set of all the activities associated with the treatment of the separate materials in the previous phase of Waste Sorting, and the transformation of these materials into inputs compatible with the specifications of the manufacturers of the 3D printers. In this way, the treatment of the materials is what will, in fact, guarantee or not the operation of this cycle as a whole.

Several techniques are currently used for the production of inputs for 3D printers. The Canadian company Re- DeTec, for example, has developed the patent for a machine called ProtoCycler, for small-scale production or for individual use, capable of shredding waste plastic and transforming the material into ABS or PLA filaments: two types of polymers that can be used as inputs for 3D printers already on the market. The Brazilian startup Print-Green3D is also developing similar techniques for the production of recycled filaments and possibly the volume of technical knowledge in this area will grow in the coming years. The same idea could be expanded to a larger scale production context associated with a selective collection system that works with large volumes of plastic waste.

3D printing with metallic materials is often done with diversified spray metals or with the "inkjet" technique. The metals commonly used for these types of printing include: stainless steel, titanium, silver and copper. There are also other printing techniques, which require different input conditions as to the state of matter and physicochemical properties. It is important to note that for the printing of mechanical components, 3D printing may not only provide the surface characteristics specified in the component design, or even material properties, such as strength.

Therefore, it is possible that other processes must be performed after printing, so that the quality of the final product is guaranteed. Some ways to manufacture metal powders for

3D printing today are atomization and the passage through chemical treatments. The atomization, in particular, can be applied to the production of various powders. In this process, molten metal is separated into fairly small droplets which are then quickly cooled before they come into contact with each other or with any other surface, and then with jets of some fluid being thrown over the droplets, they disintegrate, powder. It is possible to produce metallic powders of copper, steels, bronze, aluminum, titanium and many others in this way.

Thus, in order to create an input for the printers, the treatment of already separated waste must include the separation of metals by various chemical processes so that the dust particles can be produced, following the previous reasoning, as well as the crushing of plastics, followed material melting and transformation into polymeric filaments, for example.

Even following the example of atomization, it is possible to consider the case of stainless steel. This is a material that composes various kitchen items in the home environment. Old pots, therefore, could be a category of garbage acquired with the selective collection capable of supplying raw material for the production of inputs and printing of metal parts. For this, the steel must be properly separated and transformed into powder.

4.1.5 Product Printing

The Product Printing phase refers to all 3D printing activities that take place within the model cycle. As each printer still works with very specific inputs currently, they should receive these from the previous phase already completely ready for the printing process. That is, recycled materials must have all those physic-chemical characteristics that are necessary so that, in fact, the printing machine can operate according to the specifications of its manufacturer. This is the only way to guarantee machine life and print quality.

There are already printers capable of working with metallic inputs such as aluminum, steel and titanium, and with various polymers such as PLA polylactic acid, PETG ethylene glycol polyethylene terephthalate or PMMA polymethyl methacrylate. Even plastic PET bottles have already been turned into filaments for 3D printing. In addition, liquid resins and various composites, some of them even based on powdered wood, are currently used as input.

It is possible to conclude, therefore, that soon many materials will be compatible with those used for the production of inputs for printers, and many of these can be found within the urban environment itself. Various ferrous metals may be harnessed, as well as plastics currently dumped in landfills and discarded wood in open-pit dumps. Due to the diversity of materials and 3D printers for each type of these, a 3D printing center with several machines would be able to print a multiplicity of parts and products in general.

With 3D printing technology, it is possible to produce objects such as: architectural model miniatures, toys of all kinds, costume jewelry, engineering prototypes, medical prostheses and implants, various educational models, bottles with innovative designs, sculptures for decoration and, in addition, high value products within the industrial context, such as mechanical components for machines and robots. Within a few decades, the limitations of this printing technology should become less and less.

In addition, with the aid of other technologies and manufacturing processes, such as the micro fusion technique, it is possible to print models of complex mechanical components using a polymer input that is cheaper than a metallic input and then perform the micro fusion, with a metal alloy suitable for the operating efforts of the component. In this way, the cycle presented can provide products to a large number of customers, due to the great possibilities of production.

There are quite different techniques for 3D printing already on the market, and as this technology continues to advance, new techniques will exist in a short time. Some of the techniques that already exist are: Fused Deposition Modeling, Selective Laser Melting, Stereolithography, Electronic Beam Melting, Selective Laser Sinterig, Laminated Object Manufacturing and Digital Light Processing. The printing techniques vary according to the materials being worked and also according to the qualities required for the good to run the products.

The manufacturing center with 3D printing of the model cycle should bring together the various machines and printing techniques available to achieve the widest variety of production and thus achieve the largest possible market space. Products that are manufactured in the center can then go directly to the stage of product sales in physical stores-although the model is also compatible with an Internet sales system - or for the assembly phase, if they have been printed parts that are components of some heterogeneous final product.

4.1.6 Product Assembly

The product assembly phase, since components printed in the previous stage are provided, should basically consist of an automated assembly line that is as versatile as possible. This means that the automated assembly line must be able to assemble assorted products depending on which end product was demanded by the customer. There are already many types of industrial robots with varying workloads and degrees of freedom and high movement accuracy that can be used in the assembly stage of products described herein. One type of industrial robot commonly used in assembly plants is SCARA - Selective Compliance Assembly Robot Arm or Selective Compliance Articulated Robot Arm.

Since all of the designs proposed in the cycle are based on on-demand production and there is a wide variety of component parts that can be manufactured using 3D printers, the robotic arms used to assemble an end product must be constantly "updated" type of movements to be made for the assembly of a specific end product, the types of attachment and attachment of various components that must be made during assembly and also the different types of materials that make up the components of the final product, is more or less resilient than another with respect to tensile, torsion and compression stresses.

In this sense, in order for the automated assembly phase to be fully capable of handling varied productions and therefore successful, it is necessary to develop a thoroughly elaborated cyber-physical system that allows the management of large amounts of data from sensors and optimal decision making. After all, an optimal automated assembly phase must operate continuously to achieve productive efficiency.

Moreover, the data collected through the cyber-physical system make it possible to perform computational simulations of real production scenarios and also hypothetical scenarios, which allows the analysis of the aspects that make the assembly phase more or less profitable. The data also enables the rapid prevention and correction of operational failures, as well as unnecessary energy costs.

The assembly line sensors, which in fact allow the control and automation of the system, should be able, for example, to provide positioning signals of a part on a certain assembly stand regardless of the type of material with which the part was printed. This is important because, in this way, a single assembled final product can be composed of completely different pieces of material, thus increasing the range of product possibilities that can be generated by the cycle and also the range of possible end customers.

As the whole cycle is based on the idea of recycling, an important aspect of the assembly stage is that it is made in a way that facilitates the Waste Sorting step, by which the product will pass in a future time, without compromising the of the final product throughout its life cycle. For this to be done, it is necessary to design the parts and fittings of the final product, prior to the Printing stage, considering the process of future recycling and reuse of the part. This way of producing not only promotes an environmentally sound manufacturing ideal, but also significantly improves the efficiency of the Waste Sorting step. Also with this ideal, parts can be easily removed from the structure of assorted products, and reinserted in the assembly step into other printed structures for example, so that not only a recycling cycle is implemented, but also a cycle of reuse of components.

4.2 Study II

4.2.1 The Digital Obeya Room

Obeya is the word in Japanese for “large room”. The first use related to management was by a Toyota executive aiming a better coordination of a complex engineering initiative. To ease understanding of other workers’ opinions and facilitate its access, A3 sheets were hung up on the wall of a meeting room where each one had to write down a description of their point of view (Morgan and Liker, 2006). As other Lean practices, the Obeya room have proved to be very successful in enhancing collaboration during management processes. It helps reach decisions in a more efficient and faster way (Shabazi, Javadi, 2012), supports a meaningful reduce in waste (Terenghi et al. 2014), and help reduce organizational barriers (Oosterwal 2010). Participants can easily reach concerns and worries of other workers and reach a deeper awareness regarding problems. Therefore, a faster agreement is reached.

Employing digital systems, a contemporary adaptation of the Obeya room was developed. Underpinned by the continuous improvement motto and based on the context of visual management, Digital Obeya Room targets to enhance efficiency and productivity regarding interdisciplinary project management (Terenghi et al. 2014). Diverse engineering systems were combined aiming a more unified access to information generated in several sources (as identified by the green boxes on Figure 10). The information is loaded to an integrated relational database and linked to multidimensional visualization within the PDCA methodology.

Study II - https://doi.org/10.3846/jcem.2018.5609

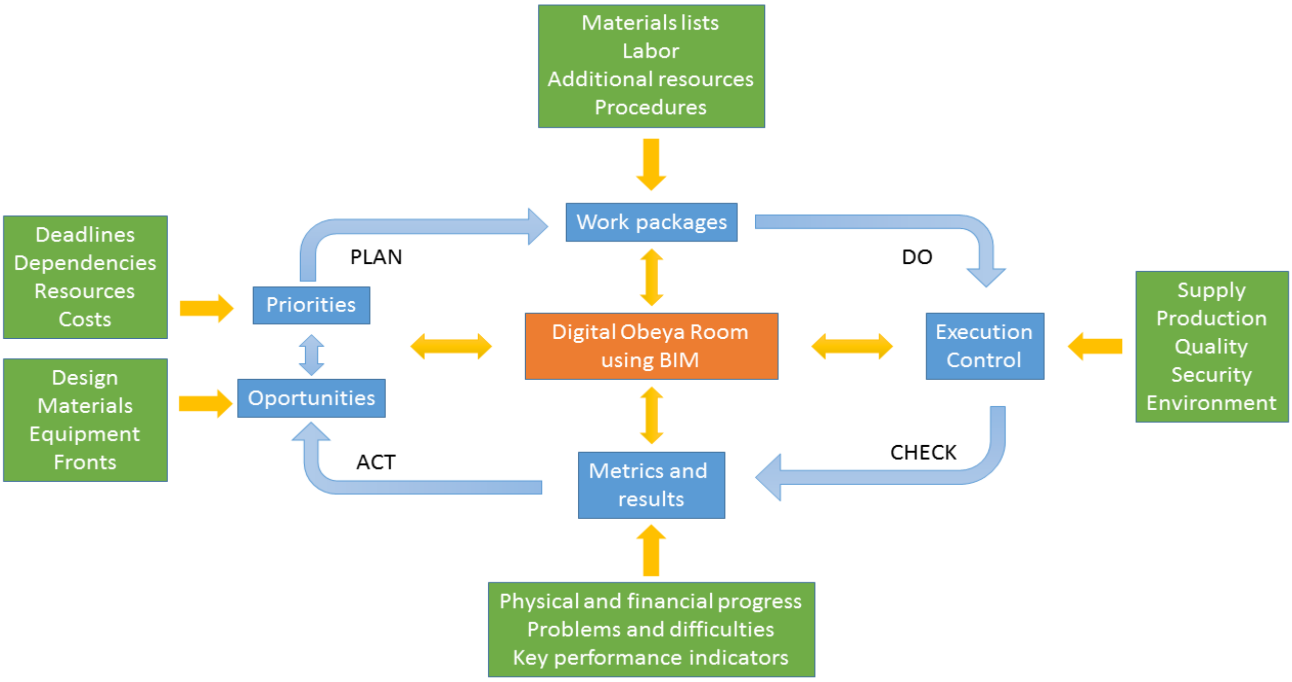


Figure 10. Framework for integration of Lean to BIM in the PDCA Cycle

The workflow (see Figure 11) aiming continuous improvement and validation of the procedures is described.

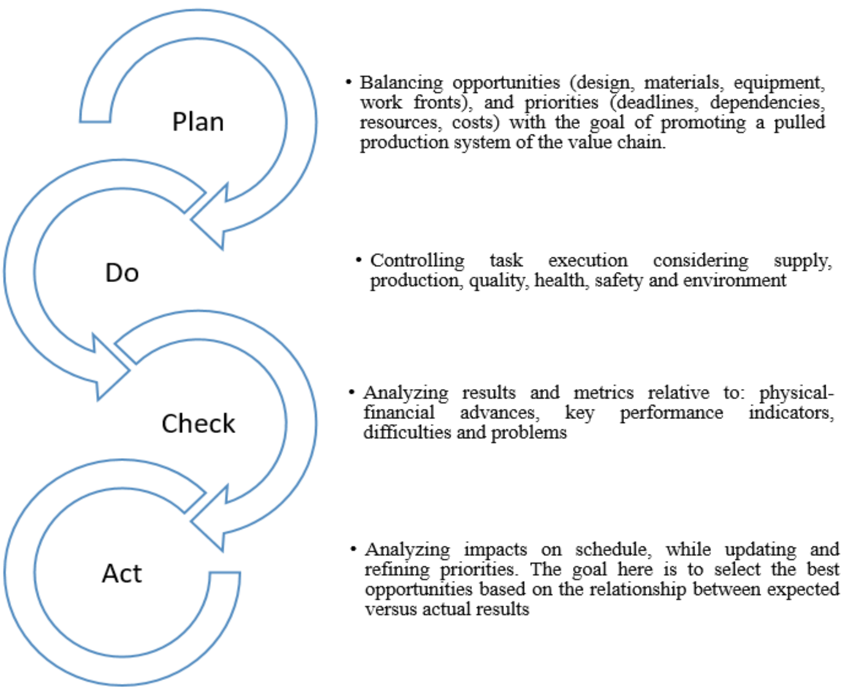


Figure 11. Standard Operational Procedure of Digital Obeya Room

Three-dimensional visualization simulates work plans and contingencies in a visual and cooperative approach throughout every PDCA step. Actions regarding PDCA reports can be taken by stakeholders supported by 3D models. These models are an efficient approach to manage tasks on every continuous improvement step. Figure 12 illustrates decision processes that occur inside the Digital Obeya Room.

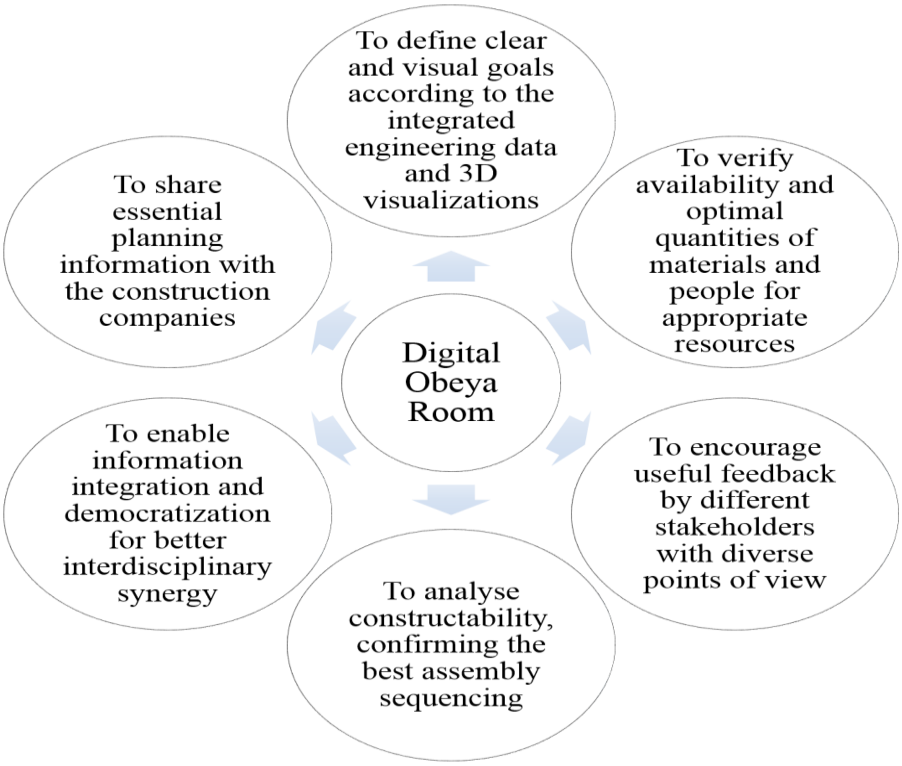


Figure 12. Guidelines in the Digital Obeya Room Model

Summarizing, this framework gives the opportunity to control available resources by physical areas and to conduct work and material flows. Constructability analysis are enhanced by the visualization system and, therefore, can determine and validate work packages. Consequently, supply management are better guided in verification of storage availability and logistics, minimizing unnecessary material movements and aiming a FIFO (first-in, first-out) approach. Related to this context, Lean mizusumashi technique can be applied to stablish better routines for material management so that workforce can focus on assembly tasks.

4.2.2 Empirical Study

The goal of this investigation was to improve maintenance processes in a scheduled stop, in a shale process plant. By applying the proposed methodology, it was possible to increase the effectiveness in communication among the project participant teams. The Digital Obeya Room provided a general overview of scheduled tasks, and contributed to reducing risks and increasing cooperation between teams. The consequences included less rework and decreased lead-time to perform tasks. Initially, data were collected from all items that required repair or replacement. This set of information was performed with the aid of the nD visualization system using computers at the shop floor. This provided an easy and practical interface to insert pending items and to have a visual control task executed through color-coding. An example of visualization is demonstrated in Figure 4, where the precise location of maintenance tasks can be identified in the 3D environment.

In this study, 16 meetings were held, containing 2 planning engineers, 1 operation supervisor, 2 maintenance engineers, and 1 Kaizen coordinator (leader of the production planning and control) for the sake of mapping pendencies, planning activities, and monitoring the maintenance stop of an industrial plant to refine the oil from the shale. The meetings happened inside the company, and the first 10 meetings were held in the morning of July 2016, according to the participants' availability, prior to the maintenance stop.

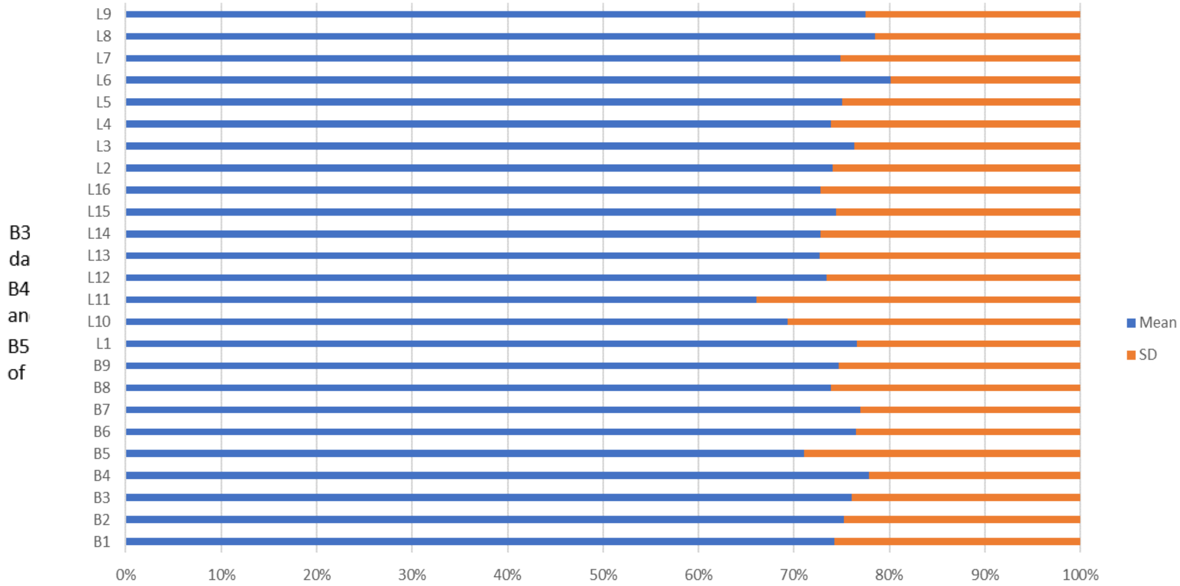
After mapping the pendencies (see Figure 13), determining the scope, and establishing the visual management in the Obeya room, there were 4 sessions every Friday at 15pm to evaluate the weekly productivity and to plan the maintenance activities of next week with the utilization of the 3D model. At the end of the project was conducted a brainstorm meeting, called lessons learned on management of knowledge workshop, to evaluate the BIM-Lean approaches on the maintenance management and determine the ones that were most beneficial during the process.

Figure 13. Collaboration between project and construction with nD viewer

The increased communication and collaboration between expert teams improved the effectiveness of item procurement and just-in-time delivery of goods. These activities followed the concept of *mizusumashi*, to mobilize teams to execute the maintenance tasks. These benefits were also established in related works (Eastman et al. 2008; Sacks et al. 2010; Nascimento et al. 2017; Nascimento et al. 2018). Moreover, in this empirical study can be noticed the application of some BIM-Lean approaches, as B6, B1, L8, and L15. At this point, it was possible to realize that the use of collaborative visual management generated greater synergy among employees to identify disputes or problems in the operation of the plant. These problems have been stored and updated on the corporate network; creating ease of information to plan future preventive maintenance shutdowns. With the definition of the work packages within a more appropriate sequencing of maintenance, it was possible to carry out this task with greater assertiveness between what was planned and done.

4.2.3 Survey results

Then, from the empirical study carried out, the principles of BIM and Lean were rated in agreement with the perceptions of the specialists of the survey. We used descriptive statistics, including frequencies and percentages, to present the results. As shown in Figure 14 and 15, BIM functionalities and Lean principles were ordered according to a measurement of position, the median. Hence, there is comparison between empirical analysis and the survey results in order to verify which BIM-Lean principle is more relevant for construction projects.



	B1	B2	B3	B4	B5	B6	B7	B8	B9	L1	L10	L11	L12	L13	L14	L15	L16	L2	L3	L4	L5	L6	L7	L8	L9
Mean	3.68	4	4	4.16	3.48	4.04	4.08	3.96	3.8	4	3.16	2.92	3.64	3.96	3.56	3.64	3.56	3.4	3.28	3.48	4.04	4.32	4.24	4.16	4.04
SD	1.28	1.32	1.26	1.18	1.42	1.24	1.22	1.4	1.29	1.22	1.4	1.5	1.32	1.49	1.33	1.25	1.33	1.19	1.02	1.23	1.34	1.07	1.42	1.14	1.17

Figure 14. Descriptive Results of most relevant BIM functionalities and Lean principles

Figure 15. BIM functionalities and Lean Principles

Figure 13 and 14 demonstrate the results from questionnaire. This figure indicates which principles of Lean principles (L1 to L16) and BIM functionalities (B1 to B9) are the most relevant to be used in the proposed framework to achieving Kaizen. The professionals perceived the practice of visual management as a significant contributor to lowering the barriers of time, cost, quality, scope, and safety. Besides that, the Figure 15 and 16 indicates

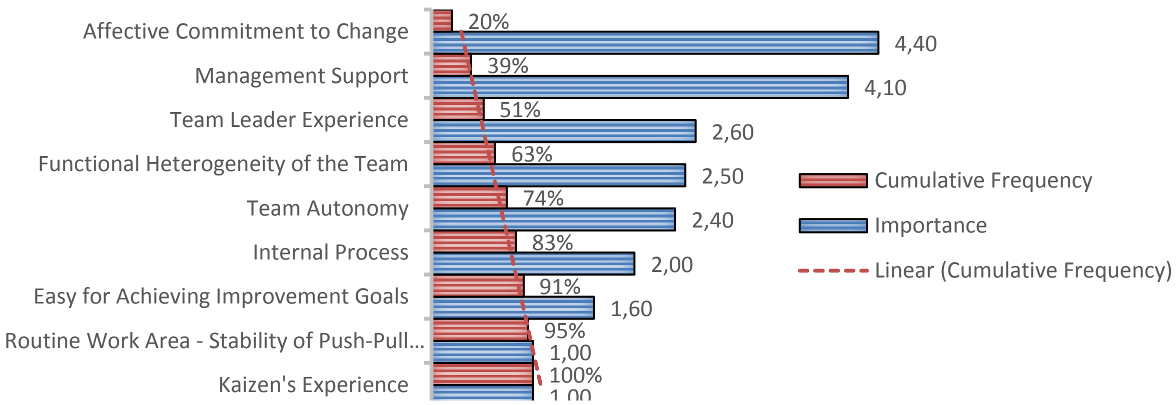


Figure 16. Most relevant attitudes of peoples to achieve kaizen

that principles and functionalities as L6, L7, L8, B4, B7, L5, L9 and B6, have stood out as fundamental to achieving continuous and incremental improvement of engineering processes in the expert's view. Above all, in order to evaluate the variables that influence the attitude of the people to the Digital Obeya Room, the importance attributed to each of them is presented in Figure 16.

It is noted that affective commitment to change and management support have stood out, however, routine work area and kaizen's experience have shown themselves to be indifferent as influencers in people's attitude. In addition, the ability of a Kaizen team should be evaluated. As the purpose of the Digital Obeya Room is to establish a continuous and incremental improvement process, the variables that influence its capacity are evaluated in Figure 17.

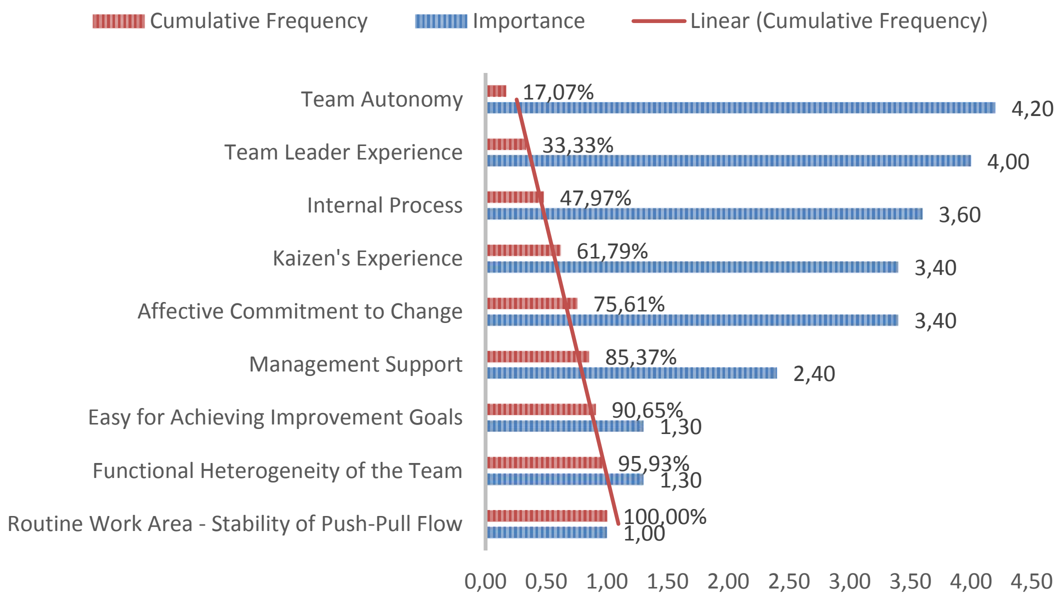


Figure 17. Most relevant capacity of team to achieve kaizen

It can be noticed that team autonomy and team leader experience stood out as influencers for the increase of the kaizen capacity of a team. However, routine work area, functional heterogeneity of the team and difficult of achieving goals were highlighted as less influential. It is worth noting that for the implementation of the proposed model, the variables presented in Figures 16 and 17 should be monitored.

4.3 Study III

This section aims to report the results of literature reviews, documents and focus groups. A triangulation is carried out with the objective of developing a framework for the implantation and training of LSS professionals in the oil and gas sector.

4.3.1 Strategic Three-Dimensional LSS Framework

Strategic planning for a sustainable LSS implementation should utilize principles, practices and lessons learned from related works. In this context, this research develops a conceptual model that relates the LP principles to the PDCA and DMAIC cycles to provide

Study III - https://doi.org/10.1108/IJLSS-02-2019-0011

an implementation guide of LSS. This model aims to provide a methodology that integrate the LP principles between stages of the PDCA and DMAIC to reach the continuous and incremental improvement of the processes, technologies, materials and people into sustainable organizations. Therefore, the LSS is explored in several areas, however, there are few works that explore their concepts in the oil and gas sector to minimize waste, which have already been accounted for in this sector at 15.8 billion dollars per year (GCR NIST, 2004).

There are several conceptual models presented in the literature for the implantation of LSS, integrating their concepts with benefits for manufacturing (Dombrowski & Mielke, 2014; Tortorella et al. 2016; Tortorella et al, 2018), sustainability (Garza-Reyes et al. 2014; Rocha-Lona et al. 2015; Chugani et al. 2017; Antony, Rodgers & Cudney, 2017; Garza-Reyes et al. 2018), lean healthcare (De Koning et al. 2006; De Mast, 2011; Cheng & Chang, 2012; Robbins et al. 2012; Wiegel & Brouwer-Hadzialic, 2015; Al Khamisi et al. 2017; Shokri, 2017), supply chain and logistics (Found & Harrison, 2012; Gutierrez-Gutierrez, De Leeuw & Dubbers, 2016; Shaaban & Darwish, 2016; Kumar & Gandhi, 2017), and construction projects (Al-Aomar, 2012). The results show that there is a need for practical guides for the implantation of LSS in the oil and gas sector, considering the characteristics of its nature for a sustainable lean journey.

For that, as a result of focus groups, literature and constructivist theory, a conceptual framework of LSS is proposed, contemplating the integration of LP principles, DMAIC (from Six Sigma) and PDCA (Kaizen) methodologies. Provides guidance on the use of LP principles by clearly guidelines and targets for greater asset life cycle efficiency, cost reduction, and continuous process improvement. Therefore, seeking to suppress some of the gaps identified in the literature, fundamentally, that concerns the lack of practical guides for the implantation of LSS in the Oil and Gas sector.

This conceptual model is intended for managers, consultants, coordinators, specialists and general leadership who seek to promote an environment of continuous and incremental improvement of industrial plants facilities and operations processes. In this context, Table 1 presents an inherent framework for the model that assesses the synergisms between LP principles and Six Sigma (DMAIC) within the PDCA cycle in favour of engineering continuous flow in the oil and gas sector. The result of Table 3 presents the LP principles in the lines, meanwhile, PDCA and DMAIC cycles in the columns, participants pointed out which LP principles are predominantly applicable (1 – true) or neutral (0 – false) to PDCA and DMAIC cycles. In the instrument of data collection, a questionnaire is carried out separating the LP principles, regarding the PDCA and, later, related to the DMAIC to analyze each concept.

LP Principles	**Plan**	**Do**	**Check**	**Act**	**Define**	**Measure**	**Analyze**	**Improve**	**Control**
	P	**D**	**C**	**A**	**D**	**M**	**A**	**I**	**C**
Variability Reduction	1	0	1	0	0	1	1	0	0
Decrease of Number of Cycles	0	1	1	0	1	1	1	1	1
Reduction of Sample Size	1	0	1	0	0	1	1	0	0
Flexibility Increase	1	1	1	1	0	0	1	1	1
Selection of an Appropriate Method of Production and Control	0	0	1	0	0	1	0	0	0
Standardization	1	1	0	0	1	0	0	0	0
Institution of Continuous Improvement	1	1	1	1	0	0	1	1	1
Visual Management Use	1	0	1	0	0	1	1	1	0
Production System Design for Value Chain Flow	1	0	0	0	1	1	1	0	0
Ensure Comprehensive Requirements Capture	0	0	1	0	1	1	0	0	0
Focus on the Concept Selection	0	1	0	0	1	0	0	1	0
Guarantee Operating Flow Requirements	0	0	1	0	0	1	1	0	1
Verification and Validation	0	0	1	0	0	1	1	0	1
Go and See for Yourself (*Gemba*)	0	1	0	0	0	0	1	0	1
Decision by Consensus, Considering all Options	0	0	1	0	1	0	0	1	0
Cultivation of an Extensive Network of Partners	0	0	0	1	1	0	0	1	0

Table 3. Synergisms between LP Principles, PDCA and DMAIC Cycles

According to the synergies between LP, Six Sigma (DMAIC) and PDCA presented in Table 3, the Strategic Tridimensional LSS Framework was developed, shown in Figure 18, which integrates the LP principles into the PDCA and DMAIC cycles, respectively. This model seeks to highlight the most relevant and/or prominent steps for applying the concepts of LP principles and Six Sigma (DMAIC) in the PDCA cycle of industrial plants throughout their life-cycle.

Figure 18. Strategic Three-Dimensional LSS Framework to Continuous Improvement

The conceptual model presented in Figure 13, aims to provide a guide to using LP principles in the PDCA cycle to implement Six Sigma through the DMAIC. In the implementation the framework highlights the most important stages of DMAIC in the PDCA cycle. To analyze and discuss about the Strategic Tridimensional LSS Framework by means of focus group from Oil and Gas workers, it's presented the discussion of results in the section as follows.

Figure 18 demonstrates a connection between a Lean-driven Performance Measurement System (PMS) and operations management methodology centered on the PDCA cycle. Configuring a sociotechnical system that integrates the Lean principles into the PDCA cycle and the DMAIC methodology to implement Lean operations management for continuous and incremental improvement. Thus, Figure 19 details the use of the DMAIC methodology to create a socio-technical PMS centered on the PDCA cycle, considering the appropriate moment of consumption of Lean principles in the management of operations.

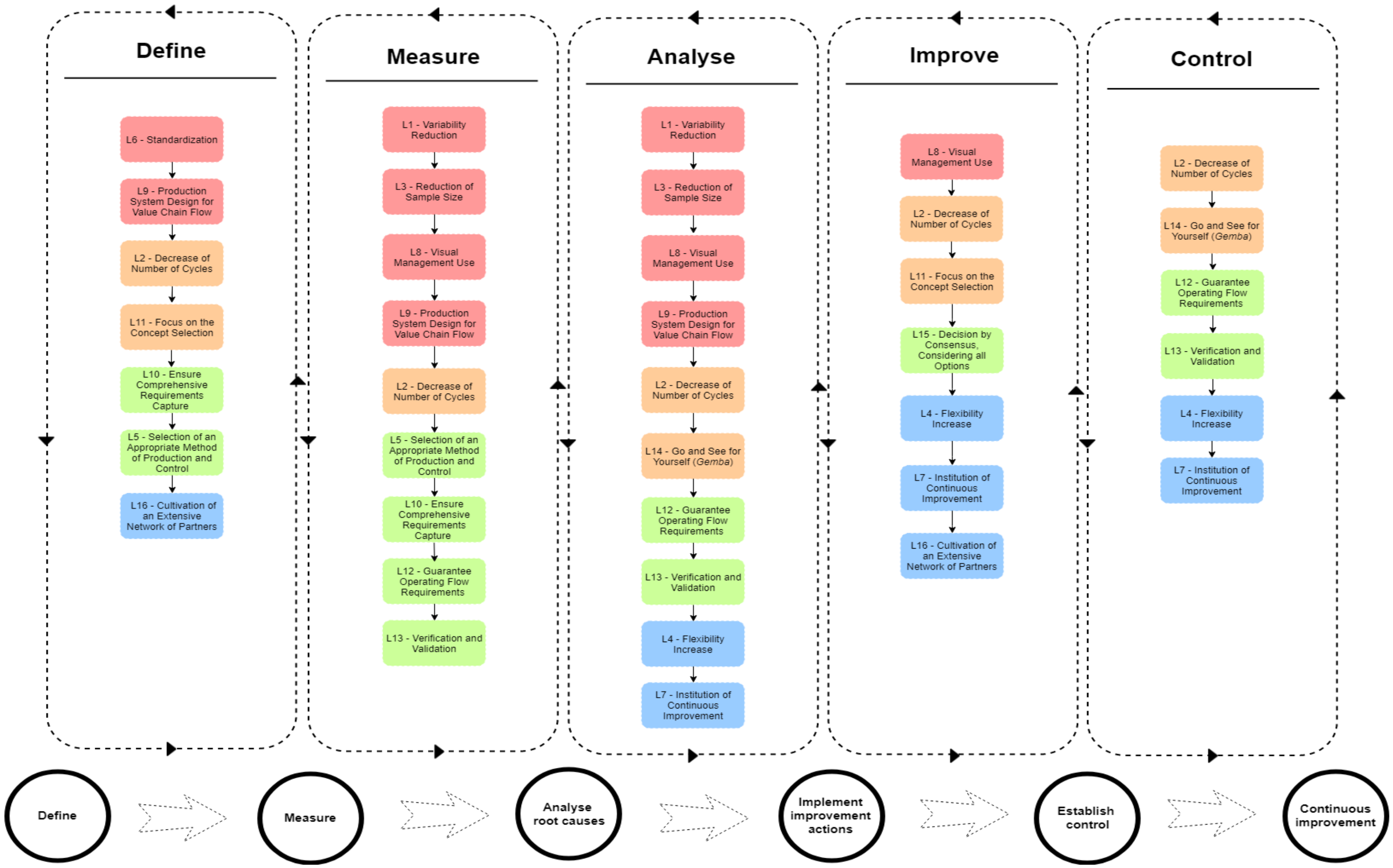


Figure 19. Strategic Tridimensional LSS Framework to Continuous Improvement

After the presentation of the LSS visual model, considering the integration between the Lean principles, PDCA cycle and DMAIC methodology, a three-dimensional strategic implementation framework of the LSS in the oil and gas sector, shown in Figure 15 is presented, thus, the deployment steps are:

(i) **Define:** standardization and production system design for value chain flow in the planning, training best practices to decrease of number of cycles and focus on the concept selection in the doing, ensure comprehensive requirements and select of an appropriate method of production and control in the checking, and cultive an extensive network of partnership in the act, completing the phases of PDCA cycle;

(ii) **Measure:** variability reduction, reduction of sample size, visual management use and production system design for value chain flow in the planning, decrease of number of cycles in the doing, select of an appropriate method of production and control, ensure comprehensive requirements capture, guarantee operating flow requirements and verification and validation in the checking;

(iii) **Analyze:** variability reduction, reduction of sample size, visual management use, production system design for value chain flow in the planning, decrease of number of cycles and go and see for yourself (gemba) in the doing, guarantee operating flow requirements and verification and validation in the checking; flexibility increase and institution of continuous improvement in the act;

(iv) **Improve:** visual management use in the planning, decrease of number of cycles and focus on the concept section in the doing, decision by consensus considering all options in the checking, cultive an extensive network of partnership, flexibility increase and institution of continuous improvement in the act;

(v) **Control:** decrease of number of cycles and go and see for yourself (gemba) in the doing, guarantee operating flow requirements and verification and validation in the checking, flexibility increase and institution of continuous improvement in the act.

From the foregoing, it can be seen that the Lean principles are consumed both in the methodological approach of operations management through the PDCA cycle and in the tooling provided by the DMAIC to provide a management system with key indicators necessary for the continuous and incremental improvement of the processes, technologies and people. The Performance Measurement System (PMS) becomes a consumer of knowledge through metrics and indicators for operations management in the oil and gas sector.

4.3.2 Discussion of Results

After presenting the Strategic Tridimensional LSS Framework, a discussion is held on each interaction between LP principles, PDCA and DMAIC cycles. These synergies generated through focus groups seek to establish a classification and methodology for the use of LP principles in the implementation of LSS in the Oil and Gas sector. The production system design for value chain flow in the perception of the participants, has direct link only with the planning stage of PDCA, since it should be used in the production system design, considering uncertainties, demand forecasting, industrial plant layout, production, workflows, among others. In this phase, the *Define (D), Measure (M) and Analyze (A)* steps of the DMAIC are used to parallel design a Performance Measurement System (PMS) that promotes the continuous and incremental improvement of the indicators inherent in the system productive. Therefore, aiming at the best combination between pushed and pulled production of the value chain in favour of waste minimization. Several authors in the literature use this principle to plan the implementation of a Lean journey (Kakehi et al. 2005; Resende et al. 2014; Che-Ani, Kamaruddin & Azid, 2018; Hailu, Mengstu & Hailu, 2018; Moumen & Elaoufir, 2018). Others report using this principle to implement Six Sigma (Bunce, Wang & Bidanda, 2008; El Haouzi, Petin & Thomas, 2009; Patti & Watson, 2010; Shaaban & Darwish, 2016).

The principle of standardization has been allocated in the planning stage to organize what can be standardized and do stage to implement the standard operating procedure (Matsui, 2005; Suárez-Barraza & Rodríguez-González, 2015). Besides, to implement DMAIC cycle inherent of *Plan (P) and Do (D)* stages, it must be use *Define* (D) step to construct measures, metrics and indicators that can analyze the variability reduction in relation to the standard process for adherence and benchmark, as well as performance of critical success indicators of all organization.

From long discussions about the steps that apply the principle and practice of visual management use, it was agreed to apply this principle in the steps of Plan and Check of the PDCA, in addition, in the steps of *Measure (M), Analyze (A)* and *Improve (I)* of the DMAIC. With the objective of using the 3D model as a central element for an effective management that uses the visual management tied to a robust and lean system of key performance indicators. For this, a parametric 3D modeling maturity level must be achieved that allows the issuance of material list, 4D analysis, information visualization, production, construction and commissioning simulations, as reported by several authors in this area (Sacks et al. 2010; Nascimento et al. 2017; Ivson et al. 2018).

The need for reduction of sample size is necessary to apply methods and practices of continuous and incremental improvement, because with the reduction of a representative sample from large sample, one can try out new methods and tools that constantly seek to reduce waste, as well as to optimize workflows (Lay, 2003; Sacks & Goldin, 2007; Sacks et al. 2010). According to the participant's perception of the focus group rounds, the reduction of the size of the sample and batch is due to the need for experimentation, besides, considering logistical constraints to supply unequivocally to get accessibility to the operation, maintenance and inspection in industrial plants facilities. This principle can be applied into *Plan (P)* and *Check (C)*stages of PDCA, meanwhile, can be used in the *Measure (M)* and *Analyze (A)* of DMAIC cycle to create a monitoring and control of new procedures, methodologies, technologies and tools.

The variability reduction can be achieved if there is a *Plan (P)* and *Check (C)*, once you have the fundamental causes defined to *Measure (M)* and *Analyze (A)* the current state, stipulate clear goals and evaluate the future scenario with cause-and-effect analysis, key performance indicators, key capacity indicators, key waste indicators, regression analysis, stochastic simulation of scenarios, reporting gains obtained in relation to the previous process and lessons learned, according to some authors in the related works (Garza-Reyes et al. 2014; Chugani et al. 2017; Garza-Reyes et al. 2018).

The establishment of an environment and dedicated staff for institution of continuous improvement was assessed by the focus group as one of the most important principles. For its implementation, the following steps must be carried out: to verify the problems, fundamental causes, to establish countermeasures for solution that must have their results constantly measured and analyzed (Modarress, Ansari & Lockwood, 2005; Chen, Li & Shady, 2010; Belekoukias et al. 2014; Glover, Farris & Van Aken, 2015; Roemeling et al. 2017; Cannas et al. 2018). According to the results of the focus groups, this principle should be applied in all stages of the PDCA, inherent in the *Analyze (A)*, *Improve (I)* and *Control (C)* stages of DMAIC, proposing continuous and incremental improvements in the production systems.

The principle of flexibility increase was pointed out in the discussions as a critical success factor to dilute the risk of uncertainties in sales, as well as increase the efficiency of industrial facilities (Mathaisel, 2006; Sacks et al., 2010). According to the results of the focus groups, this principle should be applied in all stages of the PDCA, inherent in the *Analyze (A)*, *Improve (I)* and *Control (C)* stages of DMAIC, proposing new PDCA-DMAIC approaches to provide flexible production systems for continuous improvement. The pursuit of increased flexibility applies to all stages of the management process and the performance measurement system to analyze, improve and control flexibility. Several authors point out that increasing flexibility in productive systems is a competitive factor (McDonald et al. 2009; Fang, Li & Lu, 2016; Buer, Strandhagen & Chan, 2018).

The principle that recommend go and see for yourself (*Gemba*) is a critical success factor to identify problem statement and their root causes. In addition, the empirical analysis of shop floor, construction site or industrial plant can provide clearly "broader picture" (Glover, Farris & Van Aken, 2015) of current scenario from inspected site, one of *Gemba's* main concept. Thus, improve to analyse by facts or data and identify bottlenecks, work movements, points of attention and anomalies in machines or equipment. In the empirical results from focus group, this principle is predominantly applied in the *Do (D)* stage of PDCA, besides, the *Analyze (A)* and *Control (C)* of DMAIC stages.

The focus on the concept selection is a principle that should be applied on some stages of Lean Implementation and many authors in the literature (Roemeling et al. 2017; Cannas et al. 2018; Garza-Reyes et al. 2018) relate this fact. However, in the current practices according to focus group in the oil and gas context, it is predominantly applied for *Do (D)* stage of PDCA, as well as *Define (D)* and *Improve (I)* stages of DMAIC. Since these two cycles stages are used to select the appropriated methods and tools to problem solving.

To decrease of number of cycles is necessary a continuous flow and *Jidoka* for achieve total quality, simplify the work process, minimize rework and waste, as well as reduce the lead time and cost (Modarress, Ansari & Lockwood, 2005; Roemeling et al. 2017; Cannas et al. 2018). Thus, the participants of the focus group were allocated the *Do (D)* and *Check (C)* epoxies of the PDCA, as well as all stages of the DMAIC. It should be noted that the reduction in the number of cycles is seen as a way to rationalize the execution and must be verified, systematically, mainly, creating in the stages of *Do (D)* and *Check (C)* a system of metrics, indicators, benchmarking and knowledge management through the DMAIC to provide information relevant to data analytics.

The principle of flexibility increase was pointed out in the discussions as a critical success factor to dilute the risk of uncertainties in sales, as well as increase the efficiency of industrial facilities. Focus group participants have allocated this principle at all stages of PDCA and in the *Analyze (A), Improve (I)* and *Control (C)* of DMAIC steps, since the pursuit of increased flexibility applies to all stages of the management process and the performance measurement system to analyze, improve and control flexibility. Several authors point out that increasing flexibility in productive systems is a competitive factor (McDonald et al. 2009; Fang, Li & Lu, 2016; Buer, Strandhagen & Chan, 2018).

The selection of an appropriate method of production and control is necessary to monitor the PDCA cycle through the DMAIC. In this context, the participants designated the *Check (C)* of PDCA and *Measure (M)* of DMAIC as steps that determine a suitable method for controlling the planning and operational performance measures. The methods should be validated in a pilot sample to assess their suitability for the intended context (Belekoukias, Garza-Reyes & Kumar, 2014).

A guarantee operating flow requirements is a principle that promotes the verification of the requirements to guarantee a continuous and unequivocal operational flow. Participants pointed out as applicable in the PDCA *Check (C)* stage, inherent to this stage, in the meantime, it should be used in the DMAIC stages of *Measure (M), Analyze (A)* and *Control (C)* to continuously evaluate the System Performance Measurement (SPM) and incremental improvements. It is worth emphasizing the necessity of this principle in the guarantee of unequivocal operations, according to Sacks et. al. (2009) vertically and horizontally detail all the requirements of each flow parting, performing qualitative and quantitative analyzes to ensure performability in a continuous flow.

One of the main concepts of LP is the decision by consensus, considering all options. Since it rationalizes the decision-making process in relation to the production rhythm and better choice of all specialists by consensus. Focus group participants reported that in the *Check (C)* stage, as well as in the *Define (D)* and *Improve (I)* stages of the DMAIC, they are applicable to the lean management process. Several authors advocate a good practice of lean management (Glover, Farris & Van Aken, 2015; Garza-Reyes et al. 2018).

The cultivation of an extensive network of partners is a critical success factor to

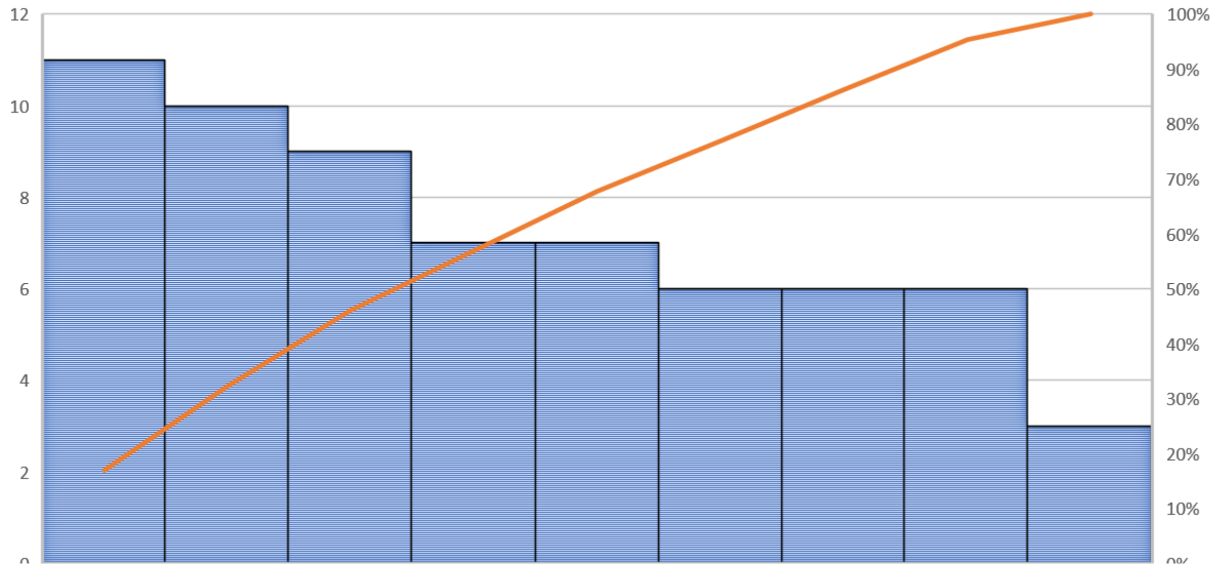


Figure 20. Pareto Chart with Frequency of LP Principles in the PDCA and DMAIC Cycles

promote an increase in the productive capacity and volume of contracts, as well as an increase in the operational and managerial competences, being able to systematically practice the *Yokoten*, that is, the horizontal management throughout the chain for continuous improvement. Participants pointed to the stage of *Act (A)*, inherent to *Define (D)* and *Improve (I)* stages of DMAIC by promoting a crowded sourcing and/or founding environment (Perdana, Suzianti & Ardi, 2017). The validation and verification principle, according to the focus group participants, is directly related to the *Check (C)* stage of the PDCA, as well as the Stages of *Measure (M), Analyze (A)* and *Control (C)* of DMAIC. As applied by some authors who explore LP principles for verification and validation (Jain et al. 2011; Azadeh et al. 2017). After presenting the framework with the best practices for the use of the three concepts LP, Six Sigma (DMAIC) and PDCA cited in favour of Kaizen, a Pareto Chart is presented in Figure 20, evaluating the frequency of LP principles most applicable in both PDCA and DMAIC cycles, according to the focus groups participants. This graph shows the most important destinations of synergies between LP principles, PDCA and DMAIC to continuous flows.

It can be noticed that the benefits of the union between the PDCA and DMAIC cycles indicated a percentage of 20.83% relative to the total LP principles to check, analyze and measure workflows. However, the PDCA concept of acting comprises only 2.08% of the total. Above all, the median or indifferent concepts in the perception of these participants, accounting for 22.22% in empirical research, were: define, improve, control, plan and do. These results denote the high applicability of these methodologies and tools for total quality management. It is worth noting that the overall applicability index of these LP principles in the cycles was 45.13% over the total possible synergy capacity.

4.4 Study IV

After extensive discussion through focus groups, the Circular VSM model is presented in Figure 21, considering unambiguous waste recycling routes using additive manufacturing practices, production rate calculation metrics, and Supply Chain 4.0 practices. to minimize movement routines between key activities of a production system.

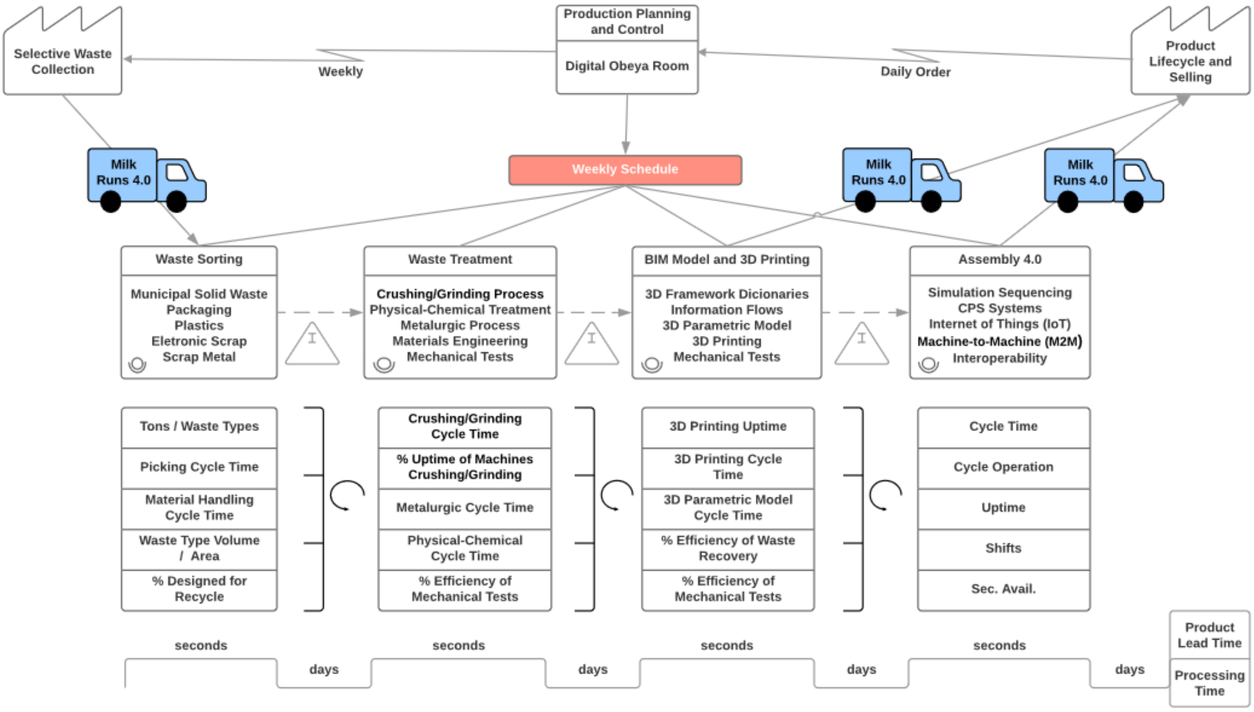


Figure 21. Cicular Value Stream Mapping of Sustainable Management System

It is verified that the model starts its key activities in the central box, called Digital Obeya Room defined by Nascimento et al. (2017), considering that the scope of work of this activity is the planning and control of the whole process through the PDCA cycle. The first aspect to be addressed is product lifecycle planning, sales volume tracking at registered stores and waste disposal monitoring through a geo-referenced smartphone application to allow you to calculate the amount, time and cost required for separate collection. of urban waste. The milk run method is used in this model with the purpose of collecting the residues by geographic region, considering the routing calculations to define the unequivocal routes, production rhythm and movement routines in the external logistics.

Once selective collection is performed, the waste is classified in intralogistics in a crossdocking area by category, using picking and material handling techniques that allow the separation and organization of waste to be designated for subsequent activities. From this, the proposed CVSM model recommends the use of supermarkets and mizusumashi practices to allow the initiation of waste treatment, seeking to turn scrap into 3D printer inputs, with minimally the same characteristics as the traditional process. In this context, it enables BIM models to be used in the digital factory to design products according to customer needs and print them with the sustainable materials that were recycled in the previous step. Finally, industry 4.0 precepts are used for industrial assembly of products and logistics in favor of destination for sales in physical or virtual stores.

4.1 Zoom and Filter

The Digital Obeya Room model advocates integrated digital management through digital information streams that exploit syntactic interoperability to traffic Model Viewer Definition (MVDs) with information that is necessary and relevant to each deliverable exchange. The Digital Obeya Room methodology is based on the Plan, Do, Check and Act (PDCA) and interdisciplinary focus group rounds for planning and controlling deliberations of both operations and asset maintenance and integrity.

The Selective Waste Collection becomes a critical success stage as it lacks a robust logistics plan, considering unambiguous routes, pace and movement routines to collect urban and industrial waste across geographic regions. Routing considers milk run principles and practices, collecting waste by geographic region and delivering it to a distribution center. The distribution center uses crossdocking methodology to organize the waste and allow for subsequent shipment.

Waste Sorting should separate waste by categories and control weight in tons, considering picking and material handling techniques to logically and traceably sort and organize waste. Waste separation should be by physical area and additional weight control should be performed with ton of waste per physical area. Finally, there is a qualitative and quantitative analysis of effective volume that can be used for subsequent stage.

The Waste Treatment stage has as its starting point the process of crushing and grinding balls, that is, a crushing and spheroidization of stored materials to meet the requirements of reusing the waste in a 3D printing. Then a metallurgical process and chemical physical treatments are performed to meet the technical specification of the customer who demanded a 3D printing of a recycled product. Finally, mechanical theses are performed to ensure that the results are equal or superior compared to the traditional process.

Since the inputs of 3D printers are recycled and available, the BIM Model and 3D Printing step recommends modeling parametric 3D to customer needs or importing a neutral file with the 3D model received by the customer, considering that the metadata are consistent to ensure correct printing of a specified material. Thus, once several separate parts are printed, an Assembly 4.0 process is performed which uses programmed robots to assemble the available parts by separate boxes with each subcomponent to compose a global component. Assembly sequencing must be defined in the 3D model, as well as torquing and other constructability and modularization rules to ensure effective assembly.

4.2 Details on Demand of Performance Measure System (PMS)

Considering the proposition of the CVSM model, it is verified that it is necessary to build a PMS of each step of the management model for the implantation of a factory. Thus, Table 4 presents a proposition of metrics for the unequivocal control of the production system.

Define	Measure
#1: Production Lifecycle and Selling	M1: Planned obsolescence amount of monthly per family / Geographic Region of Interest M2: Quantity Expected Annual obsolescence by Family / Geographic Region of Interest M3: Monthly Sales Quantity / Geographic Region of Interest M4: Annual Sales Quantity / Geographic Region of Interest
#2: Production Planning and Control	M5: Amount of Non-Value-Added Activities / Total Forecasted Activities M6: Net Operating Time Quantity (productive hours - unproductive hours) / Production Batch Item Quantity (SKUs) M7: Logistic Operating Time Amount / Gross Operating Time Amount M8: Average Quantity of Items (SKUs) Produced / Month M9: Quantity of Defective Items / Quantity of Production Batch (SKUs) M10: Quantity of Items (SKUs) Produced / Day M11: HH Allocated Quantity / Total Quantity of Production Batch (SKUs) M12: HM Allocated Quantity / Total Quantity of Production Batch (SKUs) M13: Total Material Cost / Quantity of Production Batch Items M14: Total Cost of Additional Resources / Quantity of Production Batch Items
#3: Selective Waste Collection	M15: HH Quantity Allocated for Material Handling and Picking / Quantity of Production Batch Items M16: Number of Pickup Stations in Planned Route / Total Distance of

	Planned Picking Path M17: Total Waste Volume per Collection Station / (Total Volumetric Quantity of the Collection Waste Walk * Number of Roads Available)
#4: Waste Sorting	M18: Total Weight (Ton) of Scrap Metal Recyclable / Total Weight (Ton) of Scrap Metal M20: Total Weight (Ton) of Recyclable Plastics / Total Weight (Ton) of Plastics
#5: Waste Treatment	M21: Total Weight (Ton) of Scrap Metal Recycled / Total Handling Capacity (Ton) of Scrap Metal M22: Total Weight (Ton) of Recycled Plastic / Total Weight Treatment Capacity (Ton) of Plastic M23: Total Weight (Ton) of Scrap / Total Weight (Ton) M24: Total Weight (Ton) Rework / Total Weight (Ton) M25: Net Production Time (productive working hours - unproductive hours that do not add value) / Quantity in Weight (Total) of Production Lot
#6: BIM Model and 3D Printing	M26: Total Lead Time for Parametric Modeling / Different Product Family M27: Number of Families No Subsequent Assembly Required / Total Different Product Families M28: Detailed Part Quantity / Total Part Capacity (SKUs) per month M29:Total Lead Time for 3D Printing / Different Product Family M30: Defective Parts Quantity / Total Printed Parts Quantity
#7: Assembly 4.0	M31: Quantity of Assembled Products / Working Day M32: Number of Defective Products / Working Day
#8: Milk Run 4.0	M33: Distance in Kilometers of Each Route / Quantity Stoppages for Collection and Delivery M34: Number of Picking Hours / Total Logistics Hours M35: Number of Hours in Material Handling / Total Hours of Logistics
#9: LSS Three-Dimensional Opertations	M36: Number of Planned and Not Applied Principles / Number of Principles Realized

Management	M37: Quantity of Produced Products / Quantity of Planned Products M38: Quantity of Defective Products / Quantity of Products Produced
#10: Digital Obeya Room Facility Management	M39: Quantity of Planned Activities without Workpackge / Quantity of Planned Activities M40: Number of Planned Activities Needing Asset Replacement / Number of Planned Activities

Table 4. Proposed Metrics for the CVSM Model

It can be seen that in Table 4, several metrics related to each step of the CVSM model: (i) Production Lifecycle and Selling to assess the volume, speed and variety of obsolete products available from the factory supply; (ii) Production Planning and Control, considering decision support and production capacity metrics; (iii) Selective Waste Collection, seeking logical strategy organization with performance and capacity metrics; (iv) Waste Sorting, separation of scrap metal and plastic with available stock quantity metrics; (v) BIM Model and 3D Printing, proposition of metrics for project design and 3D printing monitoring; (vi) Assembly 4.0, considering quality and performance metrics of industrial assembly; (vii) Milk Run 4.0, routing, picking and material handling metrics in CVSM logistics processes.

5 DISCUSSION

5.1 Main findings

5.1.1 Study I – Analyze the CSPS 4.0 framework

To use industry 4.0, additive manufacturing and circular economy concepts, a sequence of steps was presented in the CSPS model: (I) product life cycle; (II) selective waste collection; (III) waste sorting; (IV) waste treatment; (V) product printing; (VI) if necessary product assembly; and product selling. These steps were extensively discussed in the FGIs. The stages most questioned to the moderator as points of attention were IV and V. Stage IV the main challenge is the accomplishment of a research in metallurgical engineering to validate a physical-chemical treatment that produces the powder of input for 3D printers, printing materials in sustainable steel. In the validation, mechanical tests of both fatigue and micrographs should be performed, comparing the performance of the product between traditionally manufactured and recycled for input into 3D printing. For example, there is also a solution for recycling when it comes to cast iron, be it gray, white, nodular, malleable and/or rough (according to carbon x silicon diagram). You can sort and separate each scrap by category, as well as design a product in the 3D model to print a PMMA polymer. Thus, a microfusion process is carried out, where the scrap is heated up to 1500 degrees Celsius, reaching the liquid state and then poured onto the PMMA-printed mold. At the end, the product is put back into the oven and the mold evaporates without leaving any residue.

Step V is extensively discussed in relation to its effectiveness and type of printable materials, as well as its printing productivity and reliability in relation to products made in the traditional process. To that end, the FGIs defined that in order to validate 3D printing, the same tests as the traditional process products must be carried out and their performance in relation to quality should be evaluated. In addition, it should be noted that this step should be highlighted as strategic in the 3D modeling of the project to have greater added value and to meet the real needs of the market. This agility in being able to print the products according to the variability of the market to satisfy them, dilutes the risk of failure and increases the probability of sales of the products generated. Therefore, the use of smart production systems technologies and methodology can increase productivity and manufacturing freedom on demand, making it possible to apply just in time to sustain a continuous flow of LP. The additive manufacturing in this context is very relevant, as it makes possible the use of the circular economy by using waste or scrap to generate new products that are efficient and with high added value.

Study I - https://doi.org/10.1108/JMTM-03-2018-0071

The industry 4.0 concepts used in CSPS model are: WEB technologies, design in CAD/CAE 3D parametric tools, additive manufacturing and product assembly using robotized factories with little or no human intervention. WEB technologies are used both in the implementation of a collaborative and circular economy in society to analyze where there is each category of waste available by geography and in sales through the internet for company and/or individual. Capacity increases according to product demand, since human intervention in manufacturing is minimized and the degree of customization is high with circular additive manufacturing, being targeted to the needs of each customer. What is to be thought is the possibilities of designing products in different sectors and verifying times and movements for effective delivery within the stipulated deadlines. Therefore, the differentiation in the market and increase of the productive capacity is a highlight for this model that advocates the circular economy and application of concepts of industry 4.0 in favor of sustainable development.

5.1.2 Study II - Analyze the Digital Obeya Room

In Empirical Study, the application of the principles of collaboration in the design and B6, B1, L8 and L15 could be noticed. At this point, it was possible to realize that the use of collaborative visual management generated greater synergy among employees to identify disputes or problems in the operation of the industrial plant. These problems have been stored and updated on the intranet (corporate network); creating ease of information to plan future preventive maintenance shutdowns. With the definition of the work packages within a more appropriate sequencing of maintenance, it was possible to carry out this task with greater assertiveness between what was planned and done.

5.1.3 Study III - Analyze the LSS three-dimensional framework

The results were integrated into a three-dimensional LSS framework for sustainable operations management in the oil and gas sector to reduce waste, lead-time and cost in the life cycle of industrial plants facilities. This framework consists of a three-steps: (1) approach to collecting related works of LP principles, Six Sigma and LSS from literature and the processing of this information in order to (2) propose the preliminarily of three-dimensional LSS framework construct for industrial plants experts by focus groups, considering each opinion and (3) adjustment of three-dimensional LSS framework to discussion of results. Different LP principles are evaluated in relation to DMAIC and PDCA for effective operations management.

Study II - https://doi.org/10.3846/jcem.2018.5609

Study III - https://doi.org/10.1108/IJLSS-02-2019-0011

The most frequent principles highlighted in the focus groups as applicable are: decrease of number of cycles, Average of Frequency (AF) 77.78%, Standard Deviation (SD) 1.56%; institution of continuous improvement, AF: 77.78%, SD: 1.56%; flexibility increase, AF: 77.78%, SD: 1.56%; visual management use, AF: 55.56%, SD: 2.22%. However, the focus group less highlight fundamental principles: standardization, AF: 33.33%, SD: 2.00%; selection of an appropriate method of production and control, AF: 22.22%, SD: 1.56%. From this, is relevant pay attention on the LP principles with less frequency cited by focus groups participants. The standardization (from kaizen to standard working, man-machine separation and *jidoka*) to the autonomation and selection of an appropriate method of production and control (from stability, 5S, production levelling, takt-time pull flow and just-in-time) to the continuous flow. From this theoretical, empirical and constructivist study by triangulation of results, allows to affirm that the LP principles have been highlighted contribute to total quality and reduce waste of production systems. According to focus group, it may also be noted that few LP principles were applicable in planning and control, as well as, human aspects are little explored and/or benefited by the LP principles for continuous improvement and become critical success factors for research and development in future works.

Compared to traditional approaches of LSS implementation, such as LP principles, Six Sigma (DMAIC) and Kaizen (under PDCA) separately, the developed method combines LP principles, DMAIC and PDCA cycles. The integration results the three-dimensional LSS framework and the assessment and aggregation method can address general sustainable management systems issues, such as reduce waste, increase flexibility from materials recycling and institution of continuous improvement topics along a life-cycle of facilities. It therefore has the potential to foster monitoring and decision-making in sustainable operations management.

5.1.4 Study IV - Analyze the CVSM framework

The CVSM model unifies the three previous articles, connecting key aspects of the proposed sustainable value chain, considering in study I the conceptual model of sustainable supply chain, in study II the proposition and application of digital transformation with Digital Obeya Room model for facility managers to provide a visual management controlled system of waste generated by industry and in study III creating the LSS Three-Dimensional operations management model to reduce environmental, social and economic waste inherent of industrial plants. Therefore, in study IV the CVSM integrates materials and information by extending traditional VSM with unique metrics for a CE approach in the O&G industry.

5.2 Main implications

5.2.1 Study I

5.2.1.1 Implications to Theory

The implications of the proposed model for the environment are relevant, since urban waste is used if it is plastic or cast iron to increase the production capacity of new products, however, it has been identified that research is lacking in the direction of recycling of scrap metal, for the time being, there is no reprocessing of steel parts as input to a 3D printer. In addition, it creates a viable alternative to reuse and recycle obsolete products, rather than buying new products from non-recycled raw material. This issue has caused a focus on investment in metallurgical engineering research that recycles scrap in the exact pattern that steel 3D printers require to enable circular economy and minimize environmental impacts in the fabrication of new products. The tendency of the CSPS model is to contribute to deployment CE in the manufacture of new products or parts with additive manufacturing approaches, generating a new path of supply and demand for society. Recycling and sustainable products are new ways of circulating the economy. Above all, the local economy tends to increase, as a result, the volume of exports and imports to decrease. As the reused materials are in an urban environment and many of them are already existent in the local region, reducing the need to purchase a new product in national or international locations of a certain region. Therefore, consumers in a general manner should evaluate the financial advantages and disadvantages for decision making purposes. However, there is a significant trend for consumers to adopt sustainable practices to develop other products and/or buy sustainable products.

5.2.1.2 Implications to Practice

The socio-technical aspects are directly impacted by the CSPS management model, since it creates a new culture of reuse and recycling techniques for urban waste using 3D printing technologies, as well as 4.0 industry concepts to increase production on demand and automate manufacturing processes. In this way, design concepts can be better explored to meet what the customer really needs and what they need. In this way, Lean Thinking can be applied by specifying what customers really need and creating diverse categories in the market for product selling. Collaborators will concentrate on the technical part of recycling more and more waste and very little human intervention in circular manufacture for continuous and incremental improvement, tending to have fewer manual activities, but more time dedicated to research, development and innovation.

Study I - https://doi.org/10.1108/JMTM-03-2018-0071

5.2.2 Study II

5.2.2.1 Implications to Theory

From an academic perspective, this paper has seeks counter-measures to eliminate the gap in the literature by employing simultaneously lean principles and BIM functionalities for promote an interdisciplinary knowledge of collaborative management, and the conceptual model proposed contributes to the literature, since it can guide academics and researchers demonstrating ways in which they can use the proposed framework with the help of BIM models for an effective project control and continuous and incremental improvement of engineering processes.

5.2.2.2 Implications to Practice

Also, our findings provide a better picture to understand the critical lean and BIM principles and these analyses serves the benchmarking for future operations and strategies of construction projects. This paper contributes from a practical approach to the performability around maintenence planning, making the schedule more adherent to actual achievement timetables and improving collaboration among stakeholders. Encouraging the use of Lean and BIM principles, it was possible to level resources better based on a pull production system and reduce rework and waste throughout construction.

5.2.3 Study III

5.2.3.1 Implications to Theory

The proposed approach offers several advantages. Firstly, related works from literature, shows that LP principles, DMAIC and PDCA are explored separately (Azadeh et al. 2017). Secondly, some authors only mention that it would be relevant to integrate these concepts of LP, Six Sigma (DMAIC) and Kaizen (PDCA) for the efficient operations management in medical quality and safety (Atanelov, 2016), process (Jin & Zhao, 2010), planning (Jovanović et al. 2013), make-to-order (MTO) environment (Man, Zain & Mohd Nawawi, 2015), basic quality tools (Soković et al. 2009). Thirdly, the empirical study is applied in oil and gas sector, however, the replicability method of the framework allows to adapt and apply in different contexts. In this way, the contribution to theory takes place in an integrated three-dimensional LSS framework from which the results of their interconnections depend on the analyzed context, highlighting their dependent causality in the relationship between PDCA and DMAIC cycles with LP principles by focus group perceptions.

Study II - https://doi.org/10.3846/jcem.2018.5609

Study III - https://doi.org/10.1108/IJLSS-02-2019-0011

5.2.3.2 Implications to Practice

However, to ensure successful practical implementation of the proposed three-dimensional LSS framework is necessary to: considering key barriers to LSS, such as lack of workflows mapping; defining small sample to verification and validation; training stakeholders; developing benchmark system; and deploying technologies to process automation and autonomation (jidoka). The practical implication of the three-dimensional LSS framework focuses on industry collaborators, academics, and governments who intend to adapt this model to their context and training stakeholders with concepts, focus group discussions and Kaizen-LSS environment to deploy sustainable management systems. In addition, according to the results of the focus groups, it was noticed that human factors are little influenced by the model, that is, the LSS has low dependence with stage *Act (A)* of PDCA. Thus, within the context of processes, people, materials and technology in organizations, the most important is the affective commitment to change, considering attitudes, ideal working conditions and external factors to stabilize a Kaizen environment. Therefore, human factors stand out as a critical success factor in sustainable management systems, however, the methodology proposed in this paper has little influence in the people management to achieve success in the implementation of LSS.

5.2.4 Study IV

5.2.4.1. Implications to theory

From the theoretical perspective, our study performs an incremental improvement of a conceptual CE model presented by Nascimento et al. (2019), furthermore, explores a synergistic gap between BIM, Lean 4.0 and CE in favor of the CVSM model proposition. This model highlights its innovation by bringing together these disconnected concepts in the literature for the planning and control of a circular recycling plant. The results of the focus groups point to an empirical evidence of integration of these concepts through the CVSM model, considering applying CE practices. The literature review has shown numerous works that explore CE without considering new methodologies and technologies available in engineering, thus adhering to the precepts of digital transformation. Above all, CVSM proposes new metrics for unambiguous monitoring and control of the production system and can be implemented in different scenarios of a similar nature. In this sense, despite the notorious variation in habits, values and beliefs among members from different generations, a wide application of CE practices can override such effects and positively contribute to learning at all organizational levels.

The proposition of a model of a sustainable value chain 4.0 is a contribution to the literature, as it adds BIM functionality, manufacturing technologies and 4.0 services oriented to sustainable lean systems. Thus, several similar works explore synergisms of BIM and Lean (Sacks et al. 2010; Hamdi and Leite, 2012; Nascimento et al. 2018; Chassiakos et al. 2019; Zhang et al. 2019), Industry 4.0 and Lean (Tortorella and Fettermann, 2018; Satoglu et al. 2018; and Lai et al. 2019), but the integration of BIM, Lean and Industry 4.0 in favor of sustainable management systems is not identified. This paper proposes a waste management and control approach in the construction industry, reverse logistics using the milk run 4.0 method, planning and control through digital information management, separation and waste treatment for new design and additive manufacturing. products with high added value. Therefore, a contribution of a new manufacturing process focused on recycling scrap with additive manufacturing of high customization and low production volume products, characterizing an incremental process innovation of both manufacturing and associated service in favor of the implementation of CE practices

5.2.4.2 Implications to practice

In terms of practical implications, some contributions to managers and organizations are worth to be highlighted. Results from this study indicate that companies that extensively and approach continuous improvement initiatives are more likely to enhance their CE capabilities, regardless the upcoming generations of employees. In other words, if CE practices are properly implemented, these can generate shifts in work habits that contribute to an organizational culture where learning and knowledge sharing prevail. Thus, in this organizational context, the supposedly conflicting effects of individuals’ working preferences tend to be mitigated. Therefore, our research emphasizes the relevance of consistently lapidating behaviors through CE practices adoption, so that those behaviors are integrated into a firm’s culture and become habits that foster organizational learning.

6 CONCLUSIONS, INTERDISCIPLINARY EVIDENCES AND FUTURE PERSPECTIVES

6.1 Concluding remarks between the studies

Considering the objectives set out in the introduction of this doctoral thesis, three individual articles have been published to make possible a sustainable supply chain that justifies the creation of a factory for recycling or digital reuse. Note that the feasibility of the factory 4.0, study I, depends on the digital monitoring of facilities management, study II, to recirculate components that add value. Above all, study III explores an LSS management model that aims to standardize and monitor operations in order to increase efficiency considering the predictability of waste discards that can be directed to the digital factory in the future, study I. Therefore, a new integrated supply chain that uses Lean System methodologies, BIM technologies and Industry 4.0 concepts to create a new business model for the need for new products demanded by society.

The study I concludes that industry concepts 4.0 used in CSPS model are: WEB technologies, design in CAD/CAE 3D parametric tools, additive manufacturing and product assembly using robotized factories with little or no human intervention. WEB technologies are used both in the implementation of a collaborative and circular economy in society to analyze where there is each category of waste available by geography and in sales through the internet for company and/or individual. Capacity increases according to product demand, since human intervention in manufacturing is minimized and the degree of customization is high with circular additive manufacturing, being targeted to the needs of each customer. What is to be thought is the possibilities of designing products in different sectors and verifying times and movements for effective delivery within the stipulated deadlines. Therefore, the differentiation in the market and increase of the productive capacity is a highlight for this model that advocates the circular economy and application of concepts of industry 4.0 in favor of sustainable development.

The Study II helps both academics and practitioners decide which management strategy better suit their needs, guiding theirs actions related to prioritizing principles and describe synergies between Lean and BIM in order to enhance scheduling procedures, reduce waste, improve quality, define a precise scope for a project, avoid errors, motivate participants and promote a management effort that is supported by clear communication and shared information in the industrial plant facility sector. The results of the analysis proved to be fundamental for the management and decision-making regarding the planning and control of maintenance in facilities projects.

The Study III is systematically reviewed the literature on LP principles, Six Sigma and LSS in the oil and gas sector. This framework grouped current principles and practices in terms of their literature background, and use empirical methods for collecting and data analysis by focus group interviews for adjustment of the construct. The results were integrated into a three-dimensional LSS framework for sustainable operations management in the oil and gas sector to reduce waste, lead-time and cost in the life cycle of industrial plants operations management. This framework consists of a three-steps: (1) approach to collecting related works of LP principles, Six Sigma and LSS from literature and the processing of this information in order to (2) propose the preliminarily of three-dimensional LSS framework construct for industrial plants experts by focus groups, considering each opinion and (3) adjustment of three-dimensional LSS framework to discussion of results. Different LP principles are evaluated in relation to DMAIC and PDCA for effective operations management.

The Study IV highlights an incremental innovation in the VSM model, considering adapting new steps and metrics for circular value chain monitoring and control. Above all, we highlight the proposition of the steps of Production Lifecycle and Selling, Production Planning and Control, Selective Waste Collection, Waste Sorting, Assembly 4.0 and Milk Run 4.0 that aim to unify and generate a sustainable value chain, exploring concepts of BIM, Lean. 4.0 and CE.

6.2 Adherence to PPSIG and interdisciplinarity

This thesis is adhered to the line of research of the Postgraduate Program in Sustainable Management Systems of the Federal University of Fluminense (PPSIG / UFF), entitled "technologies in sustainable organizations". It is intended to contribute to the understanding of the points considered fundamental by the Program. The adherence to the PPSIG comes from his contribution with the scientific community on the subject studied, since it presents the representative selection of international research in an interdisciplinary area. In summary, the main distinguishing features of this doctoral thesis are the following: 1) to point out the CSPS 4.0 model that provide integration between circular economy, industry 4.0 and lean thinking to recycle scrap into the 3D prints; 2) to reduce and 3D monitoring FM in operations for predictability of scrap, waste and others by the lead time operated; and 3) proposing the three-dimensional LSS framework to deployment the LSS in oil and gas sector for waste reduction. In addition, one can also point out the adherence of this thesis to the interdisciplinarity of the PPSIG, due to the need to seek multiple perspectives on the object of study in order to understand it. That is, for the development of the three studies, it is necessary to seek theoretical support in different sciences, such as administration, statistics and engineering and thus to build an interdisciplinary path for the elaboration of the methodology that based the proposed method.

As far as the research approach is concerned, we can not only respond to the complexity of the causes of the problems, but also require new paradigms and epistemologies, a dialogue between different knowledge and the need for theoretical support in different engineering areas. Thus, there is interdisciplinarity in the objects of study and in the methodological procedures, being constituted of qualitative-quantitative research with triagulation in the data collection. It is also observed that there is a critical distance from previous theoretical and empirical knowledge, facilitating the crossing of different worldviews and accepting the learning of a new way to solve the problems already known, which allows the opening of a dialogue beyond the borders of a single discipline. Finally, this thesis was intended to be considered as an example of an interdisciplinary study for the PPSIG when referring to two of the the three facets of interdisciplinary training determined by Raynaut (2014) through the search for interdisciplinary answers to respond the complexity of the research questions, listening to professionals from different areas and different organizations during the survey and specialists during the focus group, allowing to cross different worldviews.

6.3 Limitations and suggestions for further work

6.3.1 Study I

The limitations of the present research are intended for the FGIs relied on, that is, they have local characteristics. Therefore, it is not possible to generalize the discussion of the results in a global way. However, it can be said that with the technologies of industry 4.0, such as additive manufacturing, it is possible to apply the 3 Rs (Reuse, Recycle and Reduce) by means of 3D printing of several types of materials, value added. Future research could focus on methodology and technologies to promote a BIM (Building Information Modeling) concept and CE to integrate design into the sustainable supply chain. In addition, we seek to understand this model with the lean production philosophy to reduce waste in the value chain and to validate 3D printing proposals with metallic materials from scrap in additive manufacturing.

6.3.2 Study II

As a sequence to this work, aside from the possibility of counting on a survey with a larger sample composed by more experts and applying the Digital Obeya Room model in other circumstances, we suggest the attribution of different relevance to professional according to degree of experience of current job position to obtain a more accurate perception analysis.

6.3.3 Study III

One limitation of the present paper derives from the composition of the focus groups. These consisted mainly of experts from the Brazilian academics in oil and gas industry. It is likely that a wider approach would uncover possibilities of three-dimensional LSS framework assessment that remained undetected in the focus group interviews. Looking to the future, it can be said that further research is needed to develop a set of each LP principles indicators that can be both integrated into the three-dimensional LSS framework and assessed by means of the method described above and/or survey. In addition, the three-dimensional LSS framework, together with the associated method and indicators, needs to be empirically validated and tested in other industrial sectors. Finally, there is no reason why the method proposed above cannot also be adapted, incremented with improvements applied in the industry to provide aggregation at the regional or global level.

In this context, industry 4.0 provides several clusters Hermann, Pentek & Otto (2016) that can be influenced by this model for disruptive improvement, such as: inter-connection; collaboration; standards; data analytics; information provision; and decentralized decisions.

Study I - https://doi.org/10.1108/JMTM-03-2018-0071
Study II - https://doi.org/10.3846/jcem.2018.5609
Study III - https://doi.org/10.1108/IJLSS-02-2019-0011

The central contribution of this proposed model is to rationalize the process of implementation and stabilization of a Kaizen-LSS environment, its dependence on technologies, such as industry 4.0, are exposed to boost its benefits. Once the technical-economic analysis allows for disruptive improvements, otherwise, it is possible to work on the traditional scenario of continuous and incremental improvement in each LP principle, using LSS to improve the operational performance of the production systems.

6.3.4 Study IV

Our research has some limitations that must be mentioned. With respect to sample characteristics, all focus group participants were from the universities, considering specialists in the areas of BIM, Lean 4.0 and CE. Although this research did not aim to investigate the influence of regional culture over the evaluated CVSM model, the results obtained in this study may be restricted similar socio-economic contexts. To verify the generalization of our findings and more widely validate them, further research with similar approach should be undertaken in different contexts. Additionally, the conducted data analysis was limited by the reduced sample size. Larger sample sizes could allow the application of more sophisticated multivariate data analysis techniques, such as Structural Equations Modelling (SEM), which would lead to more robust and insightful indications. Finally, we examined the effects of the CVSM on the development of manufacturing circular company planning. Nevertheless, organizational learning can also occur in companies that decided to adopt other improvement approaches instead of CE.

In this sense, further research could address the influence of generations on CVSM in empirical validation cases, considering application of the proposed model in factories 4.0 to produce a pilot scale product. Thus, allowing empirical evaluation of the advantages and disadvantages in favor of the generalization of the results in different contexts and products to serve society. Above all, implement an information management software solution at both operational and tactical levels with value chain process tracking to increase efficiency in production processes. A maturation process of this innovation requires assessing the economic viability and conceptual design of the 4.0 recycling plant and its associated value chain. As such, it allows projecting physical and financial values for investments in this potential business model that aims to manage a 4.0 recycling plant using additive manufacturing and materials technologies.

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APPENDIX I

GESTÃO INTERDISCIPLINAR DE FACILITIES A PARTIR DA INTEGRAÇÃO DE FILOSOFIA LEAN AND BUILDING INFORMATION MODELING

QUESTIONÁRIO DIAGNÓSTICO – DESEMPENHO KAIZEN DO PROJETO

1. PERFIL DO PARTICIPANTE:

1.1. Idade: ( ) menos de 18 ( ) de 18 a 30 ( ) de 31 a 40 ( ) de 41 a 50 ( ) de 51 a 60 ( ) de 61 a 70
( ) acima de 70

1.2. Gênero ( ) Masculino ( ) Feminino

1.3. Escolaridade: ( ) Ensino Fundamental ( ) Ensino Médio ( ) Ensino Superior Incompleto
( ) Ensino Superior - Completo ( ) Especialização ( ) Mestrado ( ) Doutorado ( ) Pós-doutorado

1.4. Cargo/Função:

1.5 Tipo de Projeto:

1.6. Tempo de envolvimento com Gestão: ( ) Nenhum ( ) Menos de 1 ano
( ) De 1 a 3 anos ( ) De 4 a 6 anos ( ) De 7 a 10 anos ( ) Acima de 10 anos

1.7. Em que aspectos sua organização adota ferramentas de automação de projetos / BIM? Marque somente se aplicável.
( ) Suprimento, Transportes, logística e distribuição ( ) Projeto Executivo ( ) Operação e Manutenção
( ) Construção e Montagem ( ) Em toda a empresa ( ) Outra(s), favor especificar_________________

1.9. Em que aspectos sua organização adota o *Lean Thinking*? Marque somente se aplicável.

( ) Suprimento, Transportes, logística e distribuição ( ) Projeto Executivo ( ) Operação e Manutenção
( ) Construção e Montagem ( ) Em toda a empresa ( ) Outra(s), favor especificar_________________

2. DESEMPENHO KAIZEN

2.1. A despeito dos seguintes preditores, favor ordena-los (de 1 a 9) por percepção de importância para o atingimento da capacidade kaizen do projeto? Objetivo: Verificar a ordem de importância das variáveis do projeto que mais impactaram a *capacidade kaizen - ganhos incrementais percebidos de*

conhecimento, habilidades e aptidões do empregado em resolução de problemas em um evento específico kaizen.
( ) Processos internos
( ) Autonomia da equipe
( ) Dificuldade de alcançar metas de melhoria
( ) Experiência do líder de equipe
( ) Experiência da equipe kaizen
( ) Área de trabalho "rotineira" – estabilidade do mix de produtos e grau rotineiro do fluxo de produtos;
( ) Heterogeneidade funcional da equipe*
( ) Apoio à gestão
( ) Compromisso afetivo para a mudança

2.2. A despeito dos seguintes preditores, favor ordena-los (de 1 a 9) por percepção de importância para o atingimento da atitude pró-kaizen? Objetivo: Verificar a ordem de importância das variáveis do projeto que mais impactaram a atitude – *medida de impacto da motivação dos membros da equipe para alcançar kaizen.*
( ) Processos internos
( ) Autonomia da equipe
( ) Dificuldade de alcançar metas de melhoria
( ) Experiência do líder de equipe
( ) Experiência da equipe kaizen
( ) Área de trabalho "rotineira" – estabilidade do mix de produtos e grau rotineiro do fluxo de produtos;
( ) Heterogeneidade funcional da equipe
( ) Apoio à gestão
( ) Compromisso afetivo para a mudança

2.3. Quais das seguintes ferramentas/conceitos são aplicados em sua organização?
( ) Hansei ( ) Yokoten ( ) LAMDA ( ) PDCA ( ) Mizusumashi ( ) Obeya Room
( ) Outro(s), favor especificar______________________

2.4. Qual o grau de importância do uso de práticas LEAN para o KAIZEN? Marque se aplicável, por favor.
( ) pouquíssimo importante ( ) pouco importante ( ) importante ( ) muito importante ( ) muitíssimo importante

2.5. Qual o grau de importância do uso de funcionalidades BIM para o KAIZEN? Marque se aplicável, por favor.
( ) pouquíssimo importante ( ) pouco importante ( ) importante ( ) muito importante ( ) muitíssimo importante

2.6.a Marque as 25 medidas de desempenho (16 princípios *lean* e 9 funcionalidades BIM) conforme o nível de aplicabilidade para o alcance do

KAIZEN no projeto. Objetivo: Verificar quais medidas são priorizadas para alcançar a melhoria contínua. Se não for aplicável, apenar marque NA.

1-pouquíssimo aplicável 2-pouco aplicável 3-aplicável 4-muito aplicável 5-muitíssimo aplicável

2.6.b Determine em qual fase do PDCA (*plan-do-check-act*) cada uma das 25 medidas de desempenho (16 princípios lean e 9 funcionalidades BIM) é mais relevante Objetivo: Verificar quais medidas são priorizadas dentro de cada fase do PDCA.

2.6.c Determine a ordem de importância em que cada uma das 25 medidas de desempenho (16 princípios lean e 9 funcionalidades BIM) deverá ser alcançada para o KAIZEN do projeto. Obs: Se não for aplicável não precisa ordenar.

Aplicabilidade de princípios e funcionalidades	1	2	3	4	5	NA	PDCA
Redução da variabilidade;							
Redução número de ciclos;							
Redução do tamanho da amostra;							
Aumento de flexibilidade;							
Seleção de um método apropriado de controle de produção;							
Padronização;							
Instituição de melhoria contínua;							
Uso de gerenciamento visual;							
Projeto do sistema de produção para fluxo da cadeia de valor;							
Garantia da captura compreensiva de requerimentos;							
Foco na seleção de conceitos;							
Garantia de requerimentos de fluxo operacional;							
Verificação e validação;							

Vá e veja você mesmo (Gemba);							
Decisão por consenso, considerando todas as opções;							
Cultivo de uma extensiva rede de parceiros.							
Visualização 3D (por estética e avaliação funcional);							
Geração rápida de múltiplas alternativas de projeto;							
Uso de dados do modelo para análise preditiva do edifício (análise preditiva do desempenho, estimativa de custos automatizado e avaliação da conformidade ao valor do cliente);							
Manutenção de informação e integridade do modelo (fonte de informação única, verificação de conflito automatizada);							
Geração automática de desenhos e documentos;							
Colaboração no projeto e construção (edição multiusuário de um modelo de disciplina única, visualização multiusuário de modelos multidisciplinares separados ou mesclados);							
Geração e avaliação rápidas de alternativas de planos de construção (geração automática de tarefas de construção, simulação do processo de construção, visualização 4D de cronogramas de construção);							
Comunicação baseada em objeto online/eletrônico (visualização do estado do processo, comunicação on-line de informações de produto e processo, fabricação controlada por computador, integração com o banco de dados de parceiro do projeto – cadeia de suprimentos, provisão do contexto para estado da coleta de dados no local/fora do local);							
Transferência de informação direta para apoio a fabricação controlada por computador.							

APPENDIX II

Appendix II shows the technical productions made during the PhD, considering that they are listed below:

1. Workshop between CERTI Foundation and Brazilian Air Force: https://www.decea.gov.br/?i=midia-e-informacao&p=pg_noticia&materia=ciscea-participa-de-workshop-sobre-as-competencias-em-bim
2. Lecture at the National Congress of Management Excellence: http://www.cneg.org/2017/p%C3%A1gina-est%C3%A1tica/informa%C3%A7%C3%B5es-gerais
3. Participation of the Evaluation Committee of the event "PRESENTATION OF SUPERVISED TRAINING PROJECTS" at PUC-Rio: https://www.tecgraf.puc-rio.br/publicnewsdetail/Wqpb5zgb3J9ByxSgZ
4. Coordination of Work Group 2 of the event "BUSINESS WORKSHOP ON INDUSTRY 4.0": https://www.tecgraf.puc-rio.br/publicnewsdetail/oJoy8sEBvKButv64L
5. PAPER AWARDED at IEOM UK: https://www.tecgraf.puc-rio.br/publicnewsdetail/sBSqcCyh6v9piZ7w7
6. ROUND TABLE "TALKS TO THE FUTURE" FIRJAN: https://www.tecgraf.puc-rio.br/publicnewsdetail/Jc45EspsHYmGwne3R
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