ENVIROMENTAL BENEFITS ARISING FROM THE ADOPTION OF IoT IN THE FURNITURE MANUFACTURING PROCESS

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ABSTRACT

Purpose: Verify the possible contributions of adopting IoT (Internet of Things) in the furniture manufacturing process to mitigate environmental impact.

Theoretical background: In order to build the theoretical lens to interpret the empirical data, the authors reviewed the scientific literature about Green Manufacturing, IoT Technology, as well as a characterization of the Furniture Market.

Method/design/approach: We opted for a single case study strategy, in one of the largest furniture manufacturers in Brazil, a qualitative approach, data collection through semi-structured interviews with managers of the investigated organization, directly linked to manufacturing processes, in addition to documentary survey, from internal industry records and systematic participant observation.

Results and conclusion: The research results showed that the Alfa industry adopts IoT technology, both to improve productive efficiency and to mitigate environmental impacts, in relation to better control of the energy matrix, consumption of inputs in the production process and to avoid/reduce the occurrence rework, control of internal movement and optimization of space for storing inputs and finished products.

Research implications: As managerial contributions, we highlight the set of empirical evidence that points to the technical feasibility of adopting IoT technology in the furniture manufacturing, both to improve efficiency in the production process and to mitigate the environmental impact, which can induce further academic research and thus benefit the society.

Originality/value: This is a study that is still little explored in the scientific literature.

Keywords: Environmental Impact, Furniture Industry, Internet of Things, Industry 4.0.

BENEFÍCIOS AMBIENTAIS DECORRENTES DA ADOÇÃO DA IoT NO PROCESSO DE FABRICAÇÃO DE MÓVEIS

RESUMO

Objetivo: Verificar as possíveis contribuições da adoção da IoT (Internet das Coisas) no processo de fabricação de móveis para mitigar o impacto ambiental.

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Referencial teórico: Com o intuito de construir a lente teórica, para interpretar os dados empíricos, os autores revisaram a literatura científica que versa sobre Manufatura Verde, Tecnologia IoT, bem como uma caracterização do Mercado Moveleiro.

Método: Optou-se pela estratégia de estudo de caso único, em uma das maiores fabricantes de móveis do Brasil, abordagem qualitativa, coleta de dados por meio de entrevistas semiestruturadas com gestores da organização investigada, diretamente vinculados a processos de manufatura, além de levantamento documental, a partir de registros internos da indústria e observação sistemática participante.

Resultados e conclusão: Os resultados da pesquisa evidenciaram que a indústria Alfa adota a tecnologia IoT, tanto para maior eficiência produtiva, como para mitigar os impactos ambientais, em relação ao melhor controle da matriz energética, de consumo de insumos no processo produtivo e para evitar/diminuir a ocorrência de retrabalho, de controle de movimentação interna e de otimização do espaço para armazenamento de insumos e de produtos acabados.

Implicações da pesquisa: Como contribuições gerenciais destaca-se o conjunto de evidências empíricas que apontam para a viabilidade técnica de adoção da tecnologia IoT no setor analisado, tanto para maior eficiência do processo produtivo como para mitigar o impacto ambiental, o que pode induzir mais pesquisas acadêmicas e assim beneficiar a sociedade.

Originalidade/valor: Trata-se de um estudo ainda pouco explorado na literatura científica.

Palavras-chave: Impacto Ambiental, Indústria de Móveis, Internet das Coisas, Indústria 4.0.
1 INTRODUCTION

The manufacture of furniture, along with the elaboration of clothing, footwear and food preparation, is considered one of the most traditional economic activities of mankind, since since its beginnings, the human being needed to adapt its habitat, to its best organization and to ensure its survival (Litchfield, 2011). Even if improvised, the human being adapted to the context and developed the capacity to recognize the value of the use of materials found in nature and to transform them into objects of personal use (Montenegro, 1995). Wood, found in abundance in nature, represented the main raw material in this processing process (Lopes, 2004).

Over time, with the exponential increase in the human population, associated with the improvement of cognitive capacity and scientific and technological advances, the demand of the human being for both consumables and durable goods, such as furniture, has also grown, straining the relationship of the human being with the natural environment (Oates, 1981; Litchfield, 2011; Pang & Zhang, 2019). The exploitation of natural reserves to meet the continuous and growing demand of the human population has resulted in the instability of the environment, whose most evident signs were noticed, especially, from the last century, with the occurrence of several episodes of natural disasters, in all continents (Toke & Kalpande, 2019).

Concern about the evident worsening of the environmental quality has led to the emergence of initiatives for the articulation of social groups to reflect and to make visible the risks to the environment, arising from anthropic activities, as well as to put pressure on the legal representatives, in the majority of countries, to promulgate legislation for protecting the environment. This process of linking organized civil society has intensified, especially in the last decades, with positive results (Freitas, 2012). Currently, most countries already have robust and consistent environmental protection legislation, to regulate both the lives of individuals and the actions of organizations, public or private, that generate environmental impact (Schreiber, 2023).

At the same time, scientific and technological advances, especially in recent decades, have contributed significantly to improving the living conditions of human beings, with the design and introduction of machinery and equipment in heavy and unhealthy activities, as well as for their leisure, entertainment, health and safety. Among the aforementioned advances is the worldwide computer network, the internet, especially the democratization of access to it, in the last thirty years, for companies and individuals, both through computers, and by the use of
applications in mobile equipment, such as mobile phones (Zhong et al., 2017; Xu, Xu & Li, 2018).

In the business field, the aforementioned advances in electronics and computing underpinned the development of a wide range of technologies directed towards the automation of operational processes, with a significant increase in productivity levels, efficiency, reduction of production times and volumes of waste generated (Wang et al., 2016). The profusion of new technologies, especially digital ones, motivated the group of German researchers to propose, in the year 2010, the industry 4.0 concept that brought together the set of nine specific technologies, among which is IoT (internet of things).

Organizations, especially industries, have analyzed and identified various IoT functionalities that could contribute to achieving higher levels of productive efficiency and assist in the organization and management of operational processes. In addition, recently, the potential of IoT to mitigate environmental impacts was also evidenced, following its adoption in operational processes (Sacomano et al., 2018).

From this perspective, the objective of the research was to verify the possible contributions of IoT adoption in the furniture manufacturing process to mitigate the environmental impact. The representativeness of the object analyzed motivated the methodological choice for the strategy of single case study, qualitative approach, with the collection of empirical data through in-depth interviews, participant systematic observation and documentary survey. The empirical data obtained throughout the study were submitted to content analysis.

The work begins with this introduction, being sequenced with the theoretical review on Green Manufacturing, IoT Technology and brief description of the Furniture Market. Next, the methodological path adopted in the research is detailed. The topic Analysis and discussion of results is presented below, along with the Concluding Considerations and References.

2 GREEN MANUFACTURING

The industrial activity, which is considered the second largest activity that generates environmental impacts (Riege, Staudt & Daroit, 2012; Oliveira Neto et al., 2015), unleashes several problems such as water body pollution with inadequate waste disposal, forest devastation, air pollution and global warming with greenhouse gas emissions, as well as impacts
that unbalance the food chain, impacts on human health, fauna and flora, among other harmful effects to the planet in general.

It is understood that economic systems need to sustain themselves, to maintain in equilibrium social systems, supplying human needs. However, the priority must be to maintain the natural resources that provide subsidies to previous systems, and it is in this cycle that sustainability must be established. It must be understood that modern industry, driven by the growing demand from the consumer society, is making alarming advances in the exploitation of resources at the same time as environmental degradation, caused as a result of its activity, directly compromising sustainability. In this sense, in criticism of the inertia in relation to the impacts caused, Freitas (2012) reports that economic, or social development, which denies the environmental aspects, is unsustainable.

To make a manufacturing process green, Toke and Kalpande (2019) describe some principles as key elements in achieving an effective green result. Among the aspects clarified are: the performance and engagement of the top management, the engagement and training of employees of the organization, the management and establishment of criteria for approval of suppliers, the proper management of information, investments in technologies supporting green manufacturing and logistics, as well as investment in new knowledge for employees.

For Rehman, Seth and Shrivastava (2016) the key drivers of green manufacturing are: high administration commitment, green processes, design, shopping/marketing, packaging, transportation, reverse logistics, total employee involvement, supplier management, public opinion, shareholder value, cost reduction, current and future legislation, peer pressure, cost savings, competitiveness, customer demand, supply chain pressure.

In addition to the factors highlighted, Toke and Kalpande (2019) and Pang and Zhang (2019), add that the logic of green thinking should be included in the planning of both production and purchasing policy of inputs. In the same way that one should think about the adoption of clean and renewable energy sources, the adoption of indicators for controlling and monitoring energy, wastewater, atmospheric emissions and solid waste.

Regarding the proper management of waste, Federal Law 12.305 (Brazil, 2010) that instituted the National Policy of Solid Waste (PNRS), which comprises a set of guidelines that guide Brazilian states and municipalities in the management of solid waste and suggests instruments that enable the management of the problems generated due to inadequate waste management. The PNRS aims to promote the non-generation, reduction, reuse and treatment of solid waste, as well as the environmentally sound final disposal of waste and the reduction of the use of natural resources in the production process, factors that are aligned with the principles
of the Green Manufacturing. PNRS is a support to guide industries in handling this waste with appropriate practices (Schreiber, 2023).

It should be noted that the impact of green practices and initiatives varies according to the sector. In this regard, Rehman, Seth and Shrivastava (2016) report that such practices contribute to positive outcomes in both financial and environmental performance. Green manufacturing seeks to maximize material and energy efficiency, create value from waste, transition to renewable processes, deliver functionality rather than ownership, and adopt an administration function (Bocken et al., 2014, Rehman, Seth & Shrivastava, 2016).

In general, the adoption of measures linked to the principles of green manufacturing has proved to be essential in order to contribute to an overall care for the environment, since the environmental reports show an excessive consumption of natural resources. In this sense, Wang et al. (2016) highlight two aspects about the unsustainability of the current industrial paradigm. As a first aspect, the authors explain the levels of impact of industrial production on the environment, a fact that contributes severely to global warming and the increase in environmental pollution.

In addition, Wang et al. (2016) and Schreiber (2023) report negatively on the consumption of oil and coal derivatives, non-renewable resources, as well as the aging of the population that provides a decreasing labor force. These are factors that should be considered to rethink manufacturing operating systems. Technological development can facilitate the implementation of green practices in industries, providing opportunities for the design of smart factories, with more resource-efficient systems and environmental responsibility.

3 INTERNET OF THINGS - IoT

IoT (internet-of-things) is considered a paradigmatic shift in the use of the internet, by providing its application in objects (things), allowing the sharing of real-time generated data about specific situations, subsidizing the decision-making process or intervention. In this way, it is possible to adopt predictive actions and measures, reducing risks and costs, also contributing to the sustainability of the operation (Chan et al., 2012).

Miorandi et al. (2012) state that the things that are connected to the internet assume an identity of their own, by having name and address, having capacity and relative autonomy in the process of generating and processing data, as well as actions, specific, conditioned to predefined contexts, related to the generated data. From this perspective Li et al. (2011) and Solima et al. (2016) found that the concept of IoT converges to the following structuring...
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elements: sensor, router, communication device and application/software, hosted in the cloud. It is also worth highlighting the variety of applications/programs, of monitoring, of the network of sensors and of electronic devices, which can be controlled remotely by the Internet.

Minerva, Biru and Rotondi (2015) noticed conceptual divergences of IoT and suggested its definition as a set or network of items that are necessary for the operationalization of IoT, with emphasis on sensors, software and internet. It is worth pointing out that the conception of this technology is not recent, having its origin in the seminal work of the computer scientist Mark D. Weiser, published in the magazine *Scientific American* (1991) in which he detailed the concept of ubiquitous computing, already foreseeing that computers and devices for the computational processing of data, would be adopted more and more by the industries, allowing their ubiquity, both in industrial environments, and in the day to day life of people.

In an IoT-enabled intelligent manufacturing environment, person-to-person, person-to-machine, and machine-to-machine interactions are assumed to occur. Data collection takes place in real time through networked interconnected devices (Zhong et al., 2017). IoT cannot be considered just as machine-to-machine connectivity. Its definition extends by creating an invisible smart network that can be controlled and programmed, making physical objects intelligent and communicating instantly and independently (Bongomin et al., 2020).

IoT refers to the digital interconnection of devices with the internet. Xu, Xu, and Li (2018) describe three layers in the IoT environment, namely: platform layer, application layer, and industry solution layer. The IoT platform layer connects devices to receive and transmit data and transmits information from devices to the application layer. The application layer assesses the status of the equipment and integrates IoT with cognitive processing techniques such as data analysis, automation and machine learning to assess the dynamic factors that contribute to production. Decision-making is driven by the analysis of data collected and processed through the IoT network. The industry solutions layer adds domain knowledge to the application layer.

From another perspective, Bongomin et al. (2020) present three layers as archetypal architecture, being: (i) perception layers, with sensors to acquire data, (ii) network layers acting as data transmission platform, and (iii) application layers where the intelligent environment is created. This conceptual model is corroborated by Nozari et al. (2021), as shown in Figure 1.
The first layer is represented by information generation, in which data is detected by sensors, actuators and tags, built and programmed for this purpose. In the second layer, information is shared over a wireless network. In the third layer, information processing takes place, based on specific software and different characteristics and purposes. In the last, fourth layer, the generated data is transformed into information, in a format that can be used by the end user, with support for decision making (Nozari et al., 2021).

As an example, Xu, Xu and Li (2018) cite a cement production company that applied IoT technology with advanced machine learning algorithms to estimate the trend in energy consumption. As evidenced by the results, the application has optimized the company's power consumption, reducing consumption by 10%. IoT is also known as ubiquitous computing, environmental intelligence or distributed electronics (Xu, Xu & Li, 2018).

RFID (radio frequency identification) is one of the pillars of IoT. Since the 1980s, RFID has been used to identify and track objects. It is applicable in a number of sectors, including manufacturing. In its design, RFID is a technology that uses wireless communication. Although this technology was initially developed for tracking and identification purposes, it has currently served other applications, which has led to the development of a new range of RFID-based wireless sensors (Xu, Xu & Li, 2018, Ivanov, Dolgui & Sokolov, 2019).

Summarizing the relationship between this framework of technologies, Chituc, Azevedo and Toscano (2009) and Lu (2017) mention the concept of interoperability of Industry 4.0, referring to networking, where it is possible 2 or more systems communicate and use functionalities, one another. The interoperability of Industry 4.0, can conceive the synthesis of
software, promoting solutions for the business context. The principles of interoperability are: accessibility, multilingualism, security, privacy, subsidiarity, use of open standards, open source software and multilateral solutions (Lu, 2017).

Schwab (2017) states that the predicted scenario was made possible mainly by technological advances that resulted in the reduction of the size of electronic components as well as the cost of manufacturing semiconductors, as a consequence of the scale achieved. Another characteristic that favors the adoption of IoT, according to Adi et al. (2020) is the possibility of storing the data generated in the cloud at the disposal of real-time or post-time processing. Sacomano et al. (2018) also highlight that the use of IoT can offer new business opportunities, contributing to the consolidation of the smart cities model, as well as indicating alternatives to make manufacturing sustainable. Corrêa (2019) complements the list of benefits with the realization that information can flow in both directions, enabling remote upgrades and maintenance.

4 FURNITURE MARKET

Understanding the weaknesses, identifying the threats and strengths of the furniture market, is considered essential to demonstrate the main characteristics of this economic sector. The furniture production chain is characterized by a complex panorama, with multiple inputs, such as equipment and machines, wood (preferably certified), metal, plastic, leather, foam, fabric, as main materials, being extracted, manufactured and sold, for, and by, several actors acting in the furniture supply chain, such as manufacturers, distributors and retailers (Dalalah et al., 2022). The raw materials are processed into products with various levels of integration of the raw materials, as products consisting predominantly of one of them, such as wood, metal, or complex combination of these (Silva, Massote & Lima, 2022). The products are sold to distributors and retailers, who sell them to consumers, on the domestic market or abroad. Logistic operators provide transport services for raw materials or products, from suppliers to distributors, retailers and consumers. This whole process is mediated by financing agents and must follow laws and norms that regulate relationships between suppliers and consumers, being monitored by the government and the unions.

As members of the furniture production chain, besides the industries themselves and their suppliers, financial agents and government bodies can be highlighted. According to Fiep (2017), the link between the production chain and the support sectors is essential for the development of the furniture chain. Not only are the relations between government and
companies mentioned, but also the relations between institutions with apprenticeships, unions, employers and employees.

The furniture manufacturing sector is usually classified according to the raw material most used in the production process. The classification published in 2007, carried out by the National Classification Commission (CONCLA)/Brazilian Institute of Geography and Statistics (IBGE), which administers the CNAE (National Classification of Economic Activities), published version 2.0 and presents 4 classifications, being wood, metal, other materials and mattresses (IBGE, 2021). Despite using different materials as specified in Table 1, the most common input in the furniture sector is wood. As for use, furniture is classified into residential, office and institutional (restaurants, hospitals, auditoriums, cinemas, hotels, schools and others) (Brainer, 2019).

**Table 1**

Classification of the furniture market on the basis of raw materials

<table>
<thead>
<tr>
<th>Group</th>
<th>Class</th>
<th>Subclass</th>
<th>Returns TRUE on success or FALSE on failure.</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>3101-2</td>
<td>3101-2/00</td>
<td>Furniture made predominantly of wood</td>
</tr>
<tr>
<td></td>
<td>3102-1</td>
<td>3102-1/00</td>
<td>Furniture made predominantly of metal</td>
</tr>
<tr>
<td></td>
<td>3103-9</td>
<td>3103-9/00</td>
<td>Furniture made of other materials</td>
</tr>
<tr>
<td></td>
<td>3104-7</td>
<td>3104-7/00</td>
<td>Production of mattresses</td>
</tr>
</tbody>
</table>

Source: Adapted from IBGE (2021).

The largest producers and consumers of furniture in the world are: China, the European Union and the United States (Brainer, 2019). Table 2 presents the world scenario of the main players of the furniture sector in 2017 in relation to Brazil, considering production, own consumption, export and import. In the world market, considering the volume of production, China leads with 39.3% while Brazil has a participation of only 4.03%. In relation to consumption, China occupies the top with 27.85% of the market, while Brazil represents 3.99%. Note that the values in Table 2 are expressed in the unit of millions of dollars (US$) (Brainer, 2019).

**Table 2**

Comparing the global furniture market with Brazil

<table>
<thead>
<tr>
<th>Countries</th>
<th>Production</th>
<th>%</th>
<th>Consumption</th>
<th>%</th>
<th>Export</th>
<th>%</th>
<th>Import</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>164,358</td>
<td>39.3</td>
<td>117,010</td>
<td>27.85</td>
<td>50,155</td>
<td>32.43</td>
<td>2,807</td>
<td>1.79</td>
</tr>
<tr>
<td>European Union</td>
<td>91,535</td>
<td>21.88</td>
<td>87,408</td>
<td>20.81</td>
<td>65,065</td>
<td>42.06</td>
<td>60,938</td>
<td>38.93</td>
</tr>
<tr>
<td>US</td>
<td>51,719</td>
<td>12.37</td>
<td>94,514</td>
<td>22.50</td>
<td>7,344</td>
<td>4.75</td>
<td>50,140</td>
<td>32.03</td>
</tr>
<tr>
<td>Brazil</td>
<td>16,854</td>
<td>4.</td>
<td>16,778</td>
<td>3.99</td>
<td>622</td>
<td>0.4</td>
<td>546</td>
<td>0.3</td>
</tr>
</tbody>
</table>

In addition, Table 2 shows that in the European Union countries the ratio between production and consumption results in a surplus of 4.72%. It is important to note that EU countries export 71.08% of their production, which means 42.06% of total world exports and import 38.93% of the world market for consumption. This surplus is explained by the fact that Germany and Italy are considered the countries where products with differentiated design and superior quality are manufactured, contributing to stimulate the consumption of furniture produced in their territory, being a reference for other countries. The USA and the European Union account for 70.95% of all imports, with 32.03% going to the USA alone. Brazil exports only 0.4% of world demand.

IEMI (2021) shows that the furniture sector in 2019 had approximately 19 thousand furniture manufacturers, with approximately 270 thousand people employed directly or indirectly. Brainer (2019) points out that in Brazil 46 furniture clusters in 11 states were identified: Amazonas, Bahia, Ceará, Maranhão, Pernambuco, São Paulo, Espírito Santo, Minas Gerais, Paraná, Santa Catarina and Rio Grande do Sul. Wood represents the main raw material in furniture production, which in the South region represents 88.6%; in the Midwest, 86.7%; Southeast, 85.9%; North, 82.0%; and in the Northeast, 78.7% (Brainer, 2019). According to Movergs (2020), Rio Grande do Sul is the second largest furniture producer in the country that generated 36,066 direct jobs in 2019. In 2020, the report forecast net revenues of R$ 8.22 billion. In general, we can see a growing market, in which countries such as the United States, China and countries of the European Union stand out, both in terms of consumption and production, and currently occupy a leading position. However, the market share of emerging countries is increasing in importance.

5 METHODOLOGY

In view of the objective of the research, the choice was made for a single case study strategy, in a large industry called Alfa, located in the southern region of the country. This decision of the methodological procedures finds support in authors such as Demo (2022), Flick (2012), Marconi and Lakatos (2017) and Yin (2015). In this perspective, the qualitative approach was judged to be more appropriate, due to the need to analyze the operational processes, their environmental impacts and, in the following, to analyze the environmental
benefits resulting from the adoption of IoT technology, promoting the alignment of manufacturing to the precepts of environmental sustainability.

The option for the single case study is justified by the relevance of the industry analyzed, for being the third largest manufacturer of furniture in the southern region of Brazil, which comprises three states, Rio Grande do Sul, Santa Catarina and Paraná. In the national ranking the company is among the thirty largest. This position in the ranking has remained unchanged over the last ten years, which is justified by the characteristics of the furniture industries of large size, which to increase their participation in the market would need to attract consumers from their direct competitors. This effort would require an additional investment that would be difficult to pay within the time frame considered appropriate.

As of March 2024, the company employed approximately 1,100 people, allocated to both manufacturing and administrative sectors. The production line is made of serialized furniture, upholstery, mattresses, and other related products.

The company originally started its operation only with a focus on attending to the domestic market, but, after a few years, it realized the need to turn, as well, to the foreign market. The export of furniture is a complex process, since it requires the national manufacturer to know the technical rules that regulate the commercialization of furniture in the country of destination, to promote internal adjustments both in the design of products, and in the logistic system, to make the operation viable. There is still a need to appropriate the relevant legislation, especially the protection of local consumers.

This company incorporated the service to the external market into its strategy, created a specific sector for international operations, made investments in its plant, as well as the training of people and thus managed opportunities to export its products. With continued revenue growth from exports, year after year, the percentage of overseas sales reached 9% of total revenues in the year 2023.

Considering the characterization of the need for empirical data to provide the analysis of the problem exposed and the scope of the research objective, the authors opted for the collection of data through interviews with professionals from the company who had the legitimacy to give an opinion on the theme. In order to identify and select the interviewees, a set of inclusion criteria was created, namely: (i) minimum time of 5 years of experience in the area of operations; (ii) technical training, whether at the medium level (SENAI) or higher (Engineering or Administration with a focus on Production); (iii) minimum time of 10 years in the company, in the furniture manufacturing unit or in competing industries, of the same segment; (iv) proven knowledge of industry technologies 4.0 (by means of a previously applied
questionnaire). Ten professionals were selected to be interviewed. All the interviewees are male, are in the age range of 44 to 61 years and hold management positions in the company. The individualization of the data by interviewee was prohibited by the company's management, in compliance with the regulations of the LGPD.

In order to minimize the bias of the data collection technique through interviews with the selected professionals and also to meet the premise of triangulation of empirical data sources, recommended by Yin (2015), data collection was carried out in a complementary way by means of documentary survey and participant systematic observation. The collection took place in the first half of 2023.

The empirical data obtained were submitted to content analysis, following the steps indicated by Bardin (2016). These are: (i) pre-analysis (reading of the collected material, selection of texts aligned with the objective of the research); (ii) exploration of the material (codification, categorization and enumeration); and (iii) treatment of the empirical data by means of inference and interpretation (attribution of meaning relating to the analytical categories).

6 ANALYSIS AND DISCUSSION OF RESULTS

The company Alfa Industry segment owns the upholstered business units, wooden furniture, mattresses, printing and corporate furniture. In this research were analyzed the upholstered business units and wooden furniture. The products that make up these two business units are: retractable sofas, fixed, armchairs, puff’s, reclining chairs, bedchairs, tables and dining chairs, counters, sideboards, benches, desks, crystals, framed mirrors, center tables, support tables, stools among others. It is important to understand Alfa's industrial scenario in order to understand the current context of the organization, as well as to identify the characteristics of the social environment, in which the interviewees are inserted and by which they can be influenced, as highlighted by Demo (2022), Flick (2012), Marconi and Lakatos (2017).

From this perspective, the productive areas such as metallurgy, foams, sewing of upholstery, railings and drying of wood and joinery were described and analyzed, as well as sectors considered final, i.e., the manufacturing of the ready product, furniture and upholstery, and finally, the process of shipment of the items. Completing the approach of the productive system as a whole, the activities of the support sectors considered administrative and production support areas were described. Ritzman and Krajewski (2005), Slack, Chambers and Johnston (2009), Corrêa and Corrêa (2011) and Moreira (2009) cite as administrative operations and
supporting manufacturing, operations such as planning, programming and production control, analysis of working methods, project administration and product developments among others, and which are important functions and operations for the success of any organization, since they work to reduce costs, investments, capacity increase, research and application of technological innovations, efficient utilization of physical and intellectual resources through the of operational skills and knowledge within companies. In this sense, we highlight the processes and operations of the administrative areas such as, product development, which encompasses the area of creation, modeling, engineering, sector of planning, programming and production control (PPCP), physical arrangements and project administration.

Product design/design begins with the company's designers in the creative sector. Slack, Chambers, and Johnston (2009, p. 88) state that designing a conceptual exercise that conceives of the appearance, arrangement, and structure of something before building it, however, needs to work in practice. At the Alfa company, based on the trends, inspiration from the designer and exchange of ideas with the commercial sector, the design is born, which needs the approval of the leaders of areas such as commercial and development, identifying which models will be launched at fairs and which will be created, but will not be presented at fairs, but will be launched after the fairs.

Moreira (2009) states that the development phase of the product project has several stages, from idea generation to the final project. In the Alfa company, together, starting from the initial project, the design is forwarded to modeling that makes the development of a prototype. This prototype can undergo changes during the making process according to the design until it is within the expected visual. The prototype is submitted to the validation of the commercial sector and of the PPCP, which dialog with the modeler of the product, with the coordinator of the product engineering and the designer. After approval, the product is registered in the system, along with the production instructions, which include the drawings of the parts, measurements, quantities, assembly instructions, packaging, instructions on the fiction of labels and tags among other information important for the production of the product. The program of parts that have a script in CNC machines (computer numerical control) is also drawn up so that when the product reaches the machine, it is only necessary to import the machining program. This process is aligned with the recommendations of the scientific literature on the adoption of new technologies in the furniture industry (Silva, Massote & Lima, 2022).

After, commercial and creative sector define the composition of the item and quantity to be made as pilot lot in the productive sector so that the productive sector can also make the
evaluations in terms of production. PPCP schedules the item and engineering prints the material sheets and routing that accompany the pilot being delivered to all involved sectors. When the preparation of the pilot batch is completed, the meeting takes place to evaluate the production process of the item with the presence of the PPCP coordinator, coordinator and monitor of the final sector, design, coordinator of product engineering, analyst of production engineering of the area, coordinator of the sewing area of the coating and professional of the area of creation who makes the records of the notes brought by those involved. After the meeting adjustments are made and the product is authorized for series production, following the good manufacturing practices described by Dalalah et al. (2022).

The process of making furniture consumes water and therefore the adoption of measures to reduce this consumption is considered important, from the perspective of implementing sustainable manufacturing (Litchfield, 2011). Most of the furniture industries, both in Brazil and abroad, have already implemented several controls aiming at the rational consumption of water resources that, besides having economic cost, also has inestimable social value, which is why society and its representatives (government) exert pressure on economic agents, to adopt measures to mitigate their use. Most of the initiatives undertaken include awareness-raising actions of its employees and manual controls, with installation of flow reducers, reuse of gray water, among others. However, several research studies, carried out mainly abroad, showed initiatives for the adoption of industry 4.0 technologies for the control and consequent reduction of water consumption (Dalalah et al., 2022; Lu, 2017). That is why this was the first question on the road map.

Two interviewees understood that water consumption is not relevant in the furniture industry, to justify the investment of adopting IoT technology, but they understand that technically its adoption, for this purpose, is feasible. Two interviewees realize that besides being technically feasible, the adoption of IoT technology to reduce water consumption is also a priority, from an economic and social perspective. Six interviewees agreed with the technical feasibility of IoT adoption to reduce water consumption and believe that it is relevant to adopt it, but it is not a priority. The evidenced perception is aligned with the empirical findings of Silva, Massote and Lima (2022).

As for the control of electricity consumption, of the ten interviewees, eight were unanimous, expressing their perception of both technical and economic feasibility, that is, that the investment in the adoption of IoT for this purpose would surely pay off. Only two interviewees showed themselves to be reticent, once again, with regard to viability and, therefore, to prioritization, from the economic point of view. Various studies on the topic, in
various economic activities, show that the adoption of IoT for this purpose is the most recurrent and with positive results generated in the short term (Schreiber, 2023).

A similar positioning was evidenced in the adoption of IoT technology throughout the manufacturing process, with the aim of reducing input waste and rework during the manufacturing operation. Nine interviewees were unanimous in expressing their perception of the need to prioritize the adoption of this technology, for this purpose, because they understand the adoption technically and economically viable. Only one interviewee expressed his doubts as to economic viability, understanding that the cost of waste is reduced, as well as the occurrence of rework, not justifying this investment. The scientific literature supports the perception evidenced, not only in the furniture industry, but in other economic sectors as well (Sacomano, 2018; Solima et al. 2016).

The furniture industry is recognized for unequivocal signs of air pollution, resulting from the burning of waste, fossil fuel for boilers, among other purposes (Lopes, 2004; Freitas, 2012). This practice is made visible by the surrounding community, through smoke, of varied consistency. New technologies offer solutions to mitigate impactful air emissions. However, only half of the interviewees believe that it is feasible to adopt industry 4.0 technologies for this purpose, because they understand that there is a lower cost means that can offer similar result. But another half of the interviewees understand that the adoption of traditional measures for the control, monitoring and retention of atmospheric emissions that impact on the environment are of low efficiency, and it is therefore desirable and viable, both technically and economically, to adopt industry 4.0 technologies for this purpose. Investment in IoT infrastructure is being gradually reduced, as the scale effect is consolidated, but is still relatively high, which can result in a return on investment time that exceeds expectation, as Nozari et al. evidenced. (2021), Schwab (2017) and Schreiber (2023).

Another traditional feature of the furniture industry is the intensive use of chemicals and non-recyclable inputs in the manufacturing process (Litchfield, 2011). According to the ten interviewees, both the reduction and substitution of chemicals, often toxic, as well as of non-recyclable inputs, is not something viable, not even technically, for weakening the end product, from the perspective of the benefits expected by the user. For this reason, not even the advancement of new technologies, especially the adoption of industry 4.0 technologies could contribute in this direction (Miorandi, 2012; Schreiber, 2023). Only 4 interviewees understood that the adoption of these technologies could contribute to reducing the volume of non-recyclable and toxic inputs, and 1 interviewee understood that the adoption of the technologies
could contribute to reducing the quantity of chemical products used in the process of making furniture.

The carbon footprint resulting from both internal and external logistical activities is also considered relevant by the scientific literature (Lu, 2017; Nozari et al., 2021). This finding motivated the research, in the company under analysis, of actions that could benefit from the adoption of IoT technology, from the perspective of mitigating the environmental impact, as regards reducing internal movement and also optimizing the use of internal space, for storage of inputs and finished products. All the interviewees were unanimous in stating that IoT, through sensors, interconnected in network and wifi connection, is very effective for indicating alternatives for reducing unnecessary movement, as well as for guiding the best way to take advantage of the internal space.

As for external transport and optimized use of containers and truck space, there were differences in the responses. Six interviewees perceived IoT functionalities that could contribute to mitigate environmental impact and believe that the adoption of this technology would be technically and economically feasible. Four interviewees disagreed with the perception of the relevance and economic viability of this adoption, expressing doubts regarding the efficiency of the on-board technology, to generate the results that could demonstrate the effectiveness of the carbon footprint reduction. The investment, still relatively high, for the adoption of IoT, as already highlighted, continues to be interpreted as one of the greatest obstacles, especially in processes whose costs are not commonly determined and analyzed or in outsourced activities (Silva, Massote & Lima, 2022; Schreiber, 2023).

A similar dispersion of responses was also found in relation to the questioning about the contribution of IoT to the reduction of the volume of plastic, carton and wood packaging used. Scientific literature treats the topic of packaging as a growing and relevant challenge for most organizations, in the face of obstacles to the articulation of the economic agents involved, to make reverse logistics feasible (Schreiber, Sander & Vier, 2023). In the furniture industry, packaging is considered essential for the protection of both inputs and the end product. Therefore, the researchers expected that the interviewees would recognize the relevance of the issue and suggest the adoption of new technologies, such as IoT, to help in the management of packaging. However, only four respondents were in favor of IoT adoption to support the packaging management process, as well as contribute to reducing the volume of packaging used by the company.

Adoption of the IoT to enable the reduction of the volume of liquid effluents from production and building maintenance, to be treated, as well as to increase the volume of recycled...
and reused materials, was addressed in the following, due to the emphasis that these aspects obtained in the literature review (Freitas, 2012; Silva, Massote & Lima, 2022). However, only four interviewees understand that the adoption of IoT would be relevant and feasible to generate these environmental benefits. The other interviewees, who expressed their opposition to the adoption of IoT for this purpose, justified their position based on the finding of low impact of furniture manufacturing in the generation of effluents, whether of production or of building maintenance, as well as on the reduced volume of recycled and reused materials.

The situation has changed in relation to the possibility of reducing the volume of chemicals used in the cleaning of machinery and equipment, as well as for maintenance, especially their lubrication. The interviewees stated that the type of economic activity demands intensive use of the industrial park and, consequently, demands that the machines and equipment be always in excellent state of conservation and ready for use, a finding aligned with the revised theory (Litchfield, 2011). For this reason, seven of the ten interviewees believe that the adoption of IoT is both technically and economically feasible, as well as highly recommended.

The last question sought to show whether IoT could assist in reducing the volume of waste to be destined for the landfill. This is a critical issue from a social point of view because of the rapid pace at which current landfills are moving towards sealing and unavailability due to increasing volumes of landfilled waste (Schreiber, Sander & Vier, 2023). Six interviewees expressed the same concern, indicating how the contribution of IoT technology to identifying waste that could be reused internally, whether by reuse (reintroduction into the manufacturing process) or recycling, without the need to direct the waste to a landfill, could be feasible.

Figure 1 presents the synthesis of the research results, from the three sources of empirical data collection, namely interviews, participant systematic observation and documentary survey.
## Summary of the research results

<table>
<thead>
<tr>
<th>Adoption of IoT for:</th>
<th>Interviewees</th>
<th>Observation participant</th>
<th>Withdrawal documentary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce water consumption.</td>
<td>2 - unnecessary; 2 - necessary, feasible and priority; 6 - feasible, but not priority.</td>
<td>Technically feasible, but the value of the investment returns only in the long term.</td>
<td>Discussed a few times (source - internal records).</td>
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<tr>
<td>Reduce electric power consumption.</td>
<td>8 - technically and economically feasible and priority; 2 - feasible, but not a priority.</td>
<td>Technically and economically feasible in all sectors of the enterprise.</td>
<td>Companies have already been contacted to budget for implementation, which has already occurred in some sectors.</td>
</tr>
<tr>
<td>Reduce input and rework waste during manufacturing operation.</td>
<td>9 - technically and economically feasible and priority; 1 - feasible, necessary, but not a priority.</td>
<td>Technically and economically feasible and already in the process of being implanted.</td>
<td>Deployment already occurs in some operational processes, with positive results.</td>
</tr>
<tr>
<td>Actions to control, monitor and retain atmospheric emissions.</td>
<td>5 - technically and economically feasible and priority; 5 - feasible, but not a priority.</td>
<td>Technically and economically feasible and undergoing preliminary studies for adoption.</td>
<td>Meeting registration to plan IoT deployment for this purpose.</td>
</tr>
<tr>
<td>Reduce the use of chemicals and non-recyclable inputs in the manufacturing process.</td>
<td>The characteristics of the sector hamper both actions, with or without IoT. 4 - may be feasible, but difficult to implement.</td>
<td>Furniture manufacturing is still heavily dependent on chemicals as well as non-recyclable inputs.</td>
<td>Meetings have already taken place to discuss the issue, but no progress has been made in implementing concrete actions.</td>
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<tr>
<td>Reduce internal movement and optimization of internal space use for storage of inputs and finished products.</td>
<td>The unanimous perception of the interviewees that IoT, by means of sensors, interconnected in a network and wifi connection, is very effective for indicating reduction alternatives.</td>
<td>Several sensors have already been installed in the company's premises, with a wifi connection and the data generated is used in analyzes.</td>
<td>Investments are being made in recent years, for this purpose, with evidenced and proven economic results.</td>
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<tr>
<td>Optimize external transport and container use and truck space.</td>
<td>6 - technically and economically feasible and priority; 4 - feasible, but not a priority.</td>
<td>It is clear that companies contracted for transport are endeavoring to find alternatives, to reduce costs.</td>
<td>As ALFA is large, there are many transport companies interested in the partnership. Some already use IoT to reduce costs.</td>
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<tr>
<td>Reduce the volume of used plastic, carton and wood packaging.</td>
<td>Only 4 respondents are in favor of IoT adoption to support the packaging management process, thus contributing to reduce its volume.</td>
<td>Due to the intense use of packaging, it becomes a challenge. Before adopting IoT it will be necessary to review the packaging management processes.</td>
<td>The subject of packaging is frequently discussed at meetings, in which various alternatives have already been analyzed, including the adoption of IoT. But the idea has not yet advanced.</td>
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<tr>
<td>Reduce the volume of liquid effluents from production and building maintenance to be treated and increase the</td>
<td>4 - technically and economically feasible and priority; 6 - feasible, but it is not a priority.</td>
<td>To reduce the volume of effluents, it would be necessary to review and reorganize the processes, before adopting IoT.</td>
<td>The two themes of reducing the volume of liquid effluents from production and building maintenance, as well as</td>
</tr>
<tr>
<td>Volume of recycled and reused materials.</td>
<td>Order to increase the use of recycled materials, the design of the products needs to be reviewed.</td>
<td>Greater use of recycled materials have already been dealt with in meetings, but were not prioritized, so it has not advanced, either with or without IoT.</td>
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<tr>
<td>Reduce the volume of chemicals used in cleaning machines and equipment, as well as for maintenance, especially their lubrication.</td>
<td>7 out of 10 respondents consider IoT adoption to be both technically and economically feasible, and highly recommended.</td>
<td>Despite the complexity of the process, it is considered that such investment is feasible and desirable.</td>
<td></td>
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<tr>
<td>Reduce the volume of waste going to landfill.</td>
<td>6 - technically and economically feasible and priority; 4 - feasible, but not a priority.</td>
<td>The cost of adopting IoT would be high and could take more than 10 years to pay. But it’s a viable thing.</td>
<td></td>
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</tbody>
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Source: drafted by the authors.

The results show that Alfa is aware of the environmental impacts generated by the manufacture of furniture, but due to the high complexity of the organizational structure, of operational processes already consolidated, as well as the industrial park, constituted of machines and equipment integrated in order to provide higher rate of productive efficiency, the reduction of environmental impact and carbon footprint, without or with adoption of IoT, represents a relevant challenge. However, despite this complexity and obstacles, the process of adopting new technologies, from industry 4.0, especially IoT, is ongoing and may offer important contributions to organizational sustainability.

7 FINAL CONSIDERATIONS

The manufacture of furniture is considered one of the most traditional activities of mankind, with reduced adoption of new technologies, notably in its operational processes. In addition, the furniture industry, even today, with the increasing use of certified wood and inputs from recycled waste, is an economic activity with a significant environmental impact.

In this research, carried out in one of the largest furniture industries in the country, we sought to verify the possible contributions of the adoption of IoT in the process of making furniture to mitigate the environmental impact. The empirical data were collected through in-depth interviews, with ten professionals selected according to the check-list prepared in advance and negotiated with the company, complemented with the participant systematic observation and documentary survey. The empirical data collected were submitted to content analysis.
According to the revised scientific literature and also according to the empirical data sources of the study, the furniture manufacturing process presents several critical aspects from the perspective of environmental impact. These aspects constituted, in this study, the categories of analysis, which guided the elaboration of the research instruments, both the script of questions, used in interviews, and check-list, used for participant observation and document survey.

The results of the research showed that the Alfa industry already adopts IoT technology, both for greater productive efficiency, and to mitigate environmental impacts, in relation to better control of the energy matrix, consumption of inputs in the production process and to avoid/decrease the occurrence of rework, control of internal movement and optimization of space for storage of inputs and finished products. Regarding the reduction of chemicals and lubricants used for the maintenance of machinery and equipment, the process is moving in the direction of control implementation through IoT, associated with other technologies such as cloud processing.

In the other aspects analyzed, considered relevant by the revised scientific literature, as well as some of the interviewees, the company is in the process of analysis, evaluation and planning, with different perspectives of implementation, with or without IoT. The most frequently mentioned obstacle refers to insufficiently based economic inviability or economic viability, which weakens their chances of prioritizing the allocation of financial resources.

Among the limitations of the research can be mentioned the strategy adopted, of a single case study, which even considering the representativeness of the company analyzed (one of the largest in the country) can make it difficult to generalize the results of the study. Despite this limitation, the authors believe that the results contribute to the advancement of knowledge in relation to alternatives that new technologies, especially those of industry 4.0, can offer, in various economic sectors, to mitigate the environmental impact. For this reason, it is suggested, as a continuity of research, to carry out studies with other research strategies and approaches.

REFERENCES


Environmental Benefits Arising from the Adoption of IoT in the Furniture Manufacturing Process


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