Reference Framework for Tacit Knowledge in Craft-Based Manufacturing Processes for Updating Their Practices With Digital Interventions: A Systematic Review

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Abstract
This study aimed to build a framework to define key attributes in the tacit knowledge of craft-based manufacturing processes, used to update the technique through digital interventions. Currently, with the integration of CAD/CAM technologies into craft-based processes, the development of new products is possible, but it is important to recognize the prior tacit knowledge and how they can be integrated with digital manufacturing. through a systematic literature review methodology by bibliometric technique focus on identifying case studies. Web of Science and Scopus databases was tool search, and the information was analyzed in nvivo® software for content analysis. The review indicated that technological interventions in craft-based processes consider aspects present in the skills and experience of expert people who master a technique, as well as manual gestures, strength, and movements performed during activities of the crafting process, and that allows the transformation of a material into an artifact. On the other hand, the content analysis allowed tacit knowledge to be categorized into three key atributes: skills in the knowledge of the technique, body gestures, knowledge of the material. It is concluded that to carry out a digital intervention in a craft-based process that allows guarantees the reliability of the technique, the responsible integration of the tacit knowledge of the technicians or craftsmen who dominate the process is necessary. In addition, it is concluded that despite the efforts made in the studies, not all tacit knowledge can be translated or integrated into digitization or automation, especially regarding decision-making and body gestures.

Keywords: Tacit Knowledge, Craft-Based Manufacturing , Digital Intervention, Automation

Introduction

Currently, the technologies of industries 3.0 and 4.0 transform the development of tangible products, especially those that have a manufacturing process based on craftsmanship, so that their traditional methods are intervened with CAD/CAM technological integrations, which has allowed processes that are traditionally carried out manually to switch to digital media (Bernabei & Power , 2018). In which processes that are done under the experience and manual skills of a craftsman or technician are made with CAD software and digital manufacturing in the product conceptualization and manufacturing stages. (Di Rome, 2017). Or, on the other hand, they are taken to total automation directed by robots that execute the manual tasks of the process (Ravihandar, Polydoros, Chernova, & Billard, 2019). This tendency to change new technologies in traditional practices has had three main advantages, the first is the optimization of practices in terms of avoiding reprocessing due to human error and reducing production times (Alexandre, Salguero, Peralta, & Ares., 2017) (Ismail, I, Mooney, Poolton, & Arokiam, 2007). The second is oriented toward mass customization and custom product design, given that the advantages of both methods are taken advantage from craftsmanship to flexible manufacturing and digital media allow tasks to be systematized within the process flow (Trzepieciński, 2020) (Hermann , Pentek, & Otto, 2015). And a third of an exploration of forms is based on the combination of artisanal and digital techniques for the development of complex geometries with a strong aesthetic value that would be difficult or unfeasible to carry out with conventional techniques alone (Zoran, 2013) (Bernabei & Power , 2018).

However, intervening in craft processes in this way poses significant challenges in terms of the effectiveness of emulating a craft-based technique with digital technology, since much of the knowledge for its execution resides in the experience and skills of technicians or craftsmen. who carry it out (Wood, Rust, & Horne, 2009), that is, it is of a tacit type, it is internalized in the body and mind of expert people (Polanyi, 1966), and in the artisanal context this tacit dimension is manifested in bodily and manual skills to transform a material into an artifact (Risatti, 2007). In addition, this knowledge is difficult to transfer verbally, in writing (Herschel, 2001) or codified for its systematization (Balconi, 2002), requiring a learning process to appropriate it, and in most craft-based processes time to master a technique can take several years or even decades (O'Connor, 2017). Therefore, there is a gap in how to translate this knowledge into a digital medium, either to be emulated through CAD software by replacing manual activities with computational commands (Siu & Dilnot, 2001), or to be fully automated by replacing manual labor with manual tasks. robots (Bowen, Music, Erdinc, & Shokrani, 2021).

In this sense, the purpose of this research is to define a referential framework for the type of tacit knowledge that is necessary to translate or codify in technological interventions to craft-based design and manufacturing processes, in other words, to specify in detail its characteristics in the form of key attributes through different case studies, with a systematic review of the literature, for which the following review question is posed: What characteristics of tacit knowledge are taken into account to make a digital or technological intervention of a craft-based process? On the other hand, this research also investigates how this knowledge in the form of tacit attributes is translated or codified. Consequently, we pose the second review question: How are the tacit artisanal attributes transformed/codified in a digital adaptation of the traditional method?

Materials and methods

To resolve the research questions raised, our study is based on the systematic review model proposed by Vom brocke et al (Vom Brocke, et al., 2009), due it is relevant for the structuring of knowledge and information identified in a specific domain that in the case of this work revolves around tacit knowledge. And our work describes how the articles or documents were selected for the final research report (Savino, Messeni Petruzzelli, & Albino, 2017). On the other hand, the literature review was structured in four main parts: 1 Definition of scope and context; 2 Identification of Keywords; 3 literature search 4 content analysis, these steps are based on the work carried out by (Manfredi, Frattini, Messeni, & Berner, 2018), and in turn show a systematic, replicable, and transparent approach (Greer & Lei, 2012).

In the first definition and context part, the scope of our research is in the identification of the tacit knowledge found in a craft-based process and how this knowledge is used to intervene in the process with digital technologies to improve the technique, in addition to the ways or tools that were used to translate or codify said knowledge. Furthermore, the context is found in the search for research that takes artisan-based case studies that are carried out manually, and where the technological intervention is directed by CAD / CAM technologies and automation by robots.

On the other hand, for the identification of keywords in the main concepts of tacit knowledge and craft-based manufacturing process, we made a preliminary search, in which we grouped with their thesauri, with these keywords we built the first equation in the Scopus database, which yielded 129 results that we refined by articles in English, we used a time interval from 2000 to 2022 and the following subject categories from the database were discarded: energy, earth and planetary sciences, environmental sciences, mathematics; chemistry, physics and astronomy, and immunology and microbiology, as they were not relevant to the study, this refinement reduced the equation to 81 results, of which we selected 31 documents to complete lecture by reading the title and abstract, and we found 13 relevant results. table 1 shows the inclusion and exclusion criteria for the reading and selection of articles.

Time interval	**2000-2022**
language	English or Spanish
documents	Papers with case study of craft-based process
Topic	Intervention to the process with digital technologies Tacit knowledge of the technique in the intervention with digital technologies
discarded categories in databases	energy, earth and planet sciences, environmental sciences, mathematics; chemestry, physics and astronomy, y inmunology and microbiology

Table 1: Inclusion and exclusion criteria

We also expanded the preliminary search, since we identified new keywords, this time we used the WOS database for the search, which returned 395 results, in the same way, we refined the equation excluding non-relevant thematic categories and used the same time interval, reducing the results to 139 results, of which we selected 25, which due to their total reading, 16 relevant results were identified. Table 2 details the preliminary search; Comparing the two equations we find 5 repeated results, 7 articles per snowball for a total of 31 relevant results.

Finally, with the 31 results of the preliminary part, we expanded the keywords of both groups and also added a new group of emerging technologies to the search equations, although this topic was implicit in the first searches with the aim of greater rigor. in approaching the subject we built this group with the corresponding keywords and thesauri subdivided into the technologies of CAD/CAM, digital manufacturing, and subtractive manufacturing, this wide range of technologies is identified by the various case studies where technological interventions used this type of digital media.

The final equation comprises the sum of the 3 main themes: ((((craft* OR handcraft*)OR (handmade) OR ("traditional craft") OR ("art and craft") OR (craft process*) OR (traditional process*) OR (craft method) OR (traditional method) OR (traditional practices) OR (craft practices) OR (traditional workflow) OR (craft based) OR (craft based approach)) AND (manufact* OR fabricat*OR Produc*)) AND ((cad) OR ("comput* aided design*") OR (cam) OR ("comput* aided manufact*") OR (Cax Technologies) OR (computer-aided technologies) OR (CNC machin*) OR (additive manufact*) OR (3d print*)OR (digitalization) OR (digital fabrication) OR (digital manufact*) OR (digital technology) OR (digital retrofitting) OR (digital design) OR (computational design) OR (3d technologies) OR("virtual craft") OR ("computational craft") OR ("hybrid craft") OR (converging technologies) OR (disruptive technologies) OR (rapid prototypes)) AND (("craft knowledge") OR ("know how") OR (skill*) OR ("tacit knowledge") OR ("implied knowledge") OR (“knowledge workers”))). And we ran the equation on both Scopus and WOS databases. In WOS we identified 78 results, by filtering non-relevant categories, 56 were closed, of which we selected 18 results by reading the abstract and title with 13 relevant articles. On the other hand, Scopus 214 were identified, by the same filtering the results were they closed 152 of which 30 were selected and finally we took 18 relevant documents. As shown in table 2.

<table>
<tr><td rowspan="3">Groups</td><td>Craft-based manufacturing process</td><td>(((craft* OR handcraft*)OR (handmade) OR ("traditional craft") OR ("art and craft") OR (craft process*) OR (traditional process*) OR (craft method) OR (traditional method) OR (traditional practices) OR (craft practices) OR (traditional workflow) OR (craft based) OR (craft based approach)) AND (manufact* OR fabricat*OR Produc*))</td><td colspan="2" rowspan="3">((((craft* OR handcraft*)OR (handmade) OR ("traditional craft") OR ("art and craft") OR (craft process*) OR (traditional process*) OR (craft method) OR (traditional method) OR (traditional practices) OR (craft practices) OR (traditional workflow) OR (craft based) OR (craft based approach)) AND (manufact* OR fabricat*OR Produc*)) AND ((cad) OR ("comput* aided design*") OR (cam) OR ("comput* aided manufact*") OR (Cax Technologies) OR (computer-aided technologies) OR (CNC machin*) OR (additive manufact*) OR (3d print*)OR (digitalization) OR (digital fabrication) OR (digital manufact*) OR (digital technology) OR (digital retrofitting) OR (digital design) OR (computational design) OR (3d technologies) OR("virtual craft") OR ("computational craft") OR ("hybrid craft") OR (converging technologies) OR (disruptive technologies) OR (rapid prototypes)) AND (("craft knowledge") OR ("know how") OR (skill*) OR ("tacit knowledge") OR ("implied knowledge") OR (“knowledge workers”)))</td></tr>
<tr><td>Tacit knowledge</td><td>(("craft knowledge") OR ("know how") OR (skill*) OR ("tacit knowledge") OR ("implied knowledge") OR (“knowledge workers”))</td></tr>
<tr><td>emerging technologies</td><td>((cad) OR ("comput* aided design*") OR (cam) OR ("comput* aided manufact*") OR (Cax Technologies) OR (computer-aided technologies) OR (CNC machin*) OR (additive manufact*) OR (3d print*)OR (digitalization) OR (digital fabrication) OR (digital manufact*) OR (digital technology) OR (digital retrofitting) OR (digital design) OR (computational design) OR (3d technologies) OR("virtual craft") OR ("computational craft") OR ("hybrid craft") OR (converging technologies) OR (disruptive technologies) OR (rapid prototypes))</td></tr>
<tr><td></td><td colspan="2">Databases</td><td>SCOPUS</td><td>WOS</td></tr>
<tr><td></td><td colspan="2">filtred</td><td>152</td><td>56</td></tr>
<tr><td></td><td colspan="2">fully read</td><td>30</td><td>18</td></tr>
<tr><td></td><td colspan="2">Relevant</td><td>18</td><td>13</td></tr>
</table>

Table 2: Final equation

Analysis of content and results

Once we read all the relevant documents found both in the preliminary and final search, for the content analysis we classified each of the study cases found in the documents by groups and subgroups, this classification helped to find the key attributes of tacit knowledge that It was necessary to use the different techniques for the digital interventions, and from the key attributes, we found the tools or ways by which this knowledge was translated or used in the digital environment. The following sections describe the analysis process.

Due to the variety of the study cases found in the systematic review, we classify them according to the digital intervention approach, 3 groups were found: 1. CAD/CAM digital adaptation that corresponds to interventions where the craft-based technique is modified by CAD modeling software, in some cases obtaining reference models by reverse engineering, and the use of digital manufacturing, either additive or subtractive; 2. Robots for automation This group refers to studies that try to intervene in the craft-based process so that there is total automation without the intervention of humans and carried out by robotic arms that imitate manual operations; 3 Exploratory of traditional techniques with digital technologies, this last group refers to a mixture of both techniques with more exploratory purposes of developing new forms or artifacts from the combination of both techniques in a kind of digital craft. In the same way, in each main group, the case studies are organized according to their area, respectively, we identify Medical devices, architecture, carving, metal work, and other techniques that were not possible to group as Basketry, traditional glass, Ceramics, footwear. , pattern making for dressmaking, manufacture of fiberglass molds. Figure1 illustrates the categorization carried out.

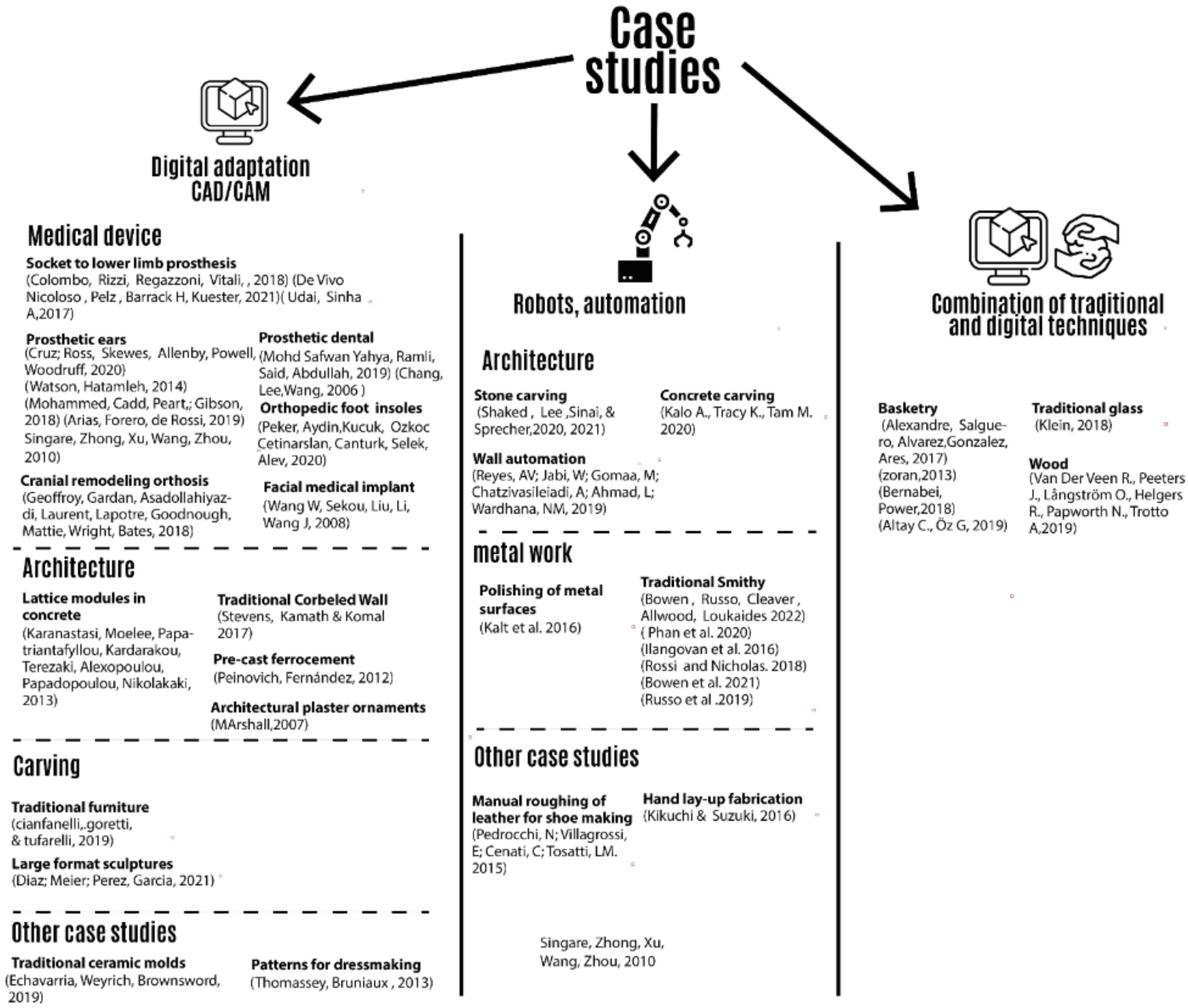

Figure 1: Characterization of the case studies

Digital adaptation CAD/CAM

The case studies grouped in this category showed the integration of CAD/CAM technologies in their craft-based workflows, updating their techniques allowing the development of custom products, or mass customization, on the other hand, the integration tries to reduce costs and time in addition to reducing the specialized knowledge in its operations, that is, the tacit nature, to facilitate the development of the technique. Next, we describe the subgroups regarding the nature of their craft-based process and technological intervention.

Medical devices

In this area we identify orthosis and prosthesis manufacturing processes oriented to custom design for medical cases, where adjustment with the patient's body is necessary for its use, in the case of sockets for lower limb prostheses, it refers to the development of the component socket that is the interface between the patient's body and the prosthesis that replaces a lost lower extremity, and its design is made taking into account the geometry of the patient, loading and unloading regions where there are bony protuberances or nerve endings, the lifestyle of the patient among others (Herbert, Simpson, William, & Ion, 2005) (Mak et al, 2001). On the other hand, the ear prosthesis is used when a person loses this part of the body or is born with some malformation (Mohammed, Cadd, Peart, & Gibson, 2018) (Cruz, et al., 2020) (Watson, Muhanad, & Hatamleh , 2014) (Arias, Forero, & Estrada, 2019) (Singare, Zhong, Xu, Wang, & Zhou, 2010). Dental prostheses are used to replace missing teeth in patients (Mohd, Ramli, Said, & Abdullah, 2019) (Chang, Lee, & Wang, 2006). In the case of cranial remodeling orthosis, it is used in patients under one year of age when there is a malformation in the patient's head and this device allows the head to mold to the orthosis as the patient grows, recovering the normal shape of the skull (Geoffroy, and others, 2018). Orthopedic inserts are used to correct defects in the foot and allow the patient to walk normally (Peker, et al, 2020). And medical facial implants are used in medical procedures to correct defects that require taking data on the geometry of the bone, which serves as the basis for sculpting or custom designing the implant (Wang, Sekou, Liu, Li, & Wang , 2008).

Although the case studies of medical devices are different, their flow of operations in the craft manufacturing process is very similar and is guided by: 1. Obtaining the geometry of the human body with plaster bandages (negative mold), the only A different case was that of the cranial remodeling orthosis, where the data was collected from the patient's positive mold due to the difficulties of scanning a child under one year of age (Geoffroy, et al., 2018). 2 positive mold by emptying, and 3 modification of the mold according to the case study, 4 thermoforming of the mold and final finishes; In turn, the intervention with technologies is carried out in a general way in all the study cases by obtaining reference models of the part of the human body of interest, which in some cases was carried out by 3D scanning and in others by CT (computer tomography), refinement of the mesh, modification of the geometry of the model according to the patient's specifications, and 3D printing of the orthosis or prosthesis (Colombo, Rizzi, Caterina, Daniele, & Vitali, 2018) (Nicoloso, Pelz, Barrack, & Kuester, 2021) (Udai & Sinha, 2017), in the case study of ear prostheses, after this process, an artisan process of lost-wax casting of the printed model was continued (Mohammed, Cadd, Peart, & Gibson, 2018) (Cruz, et al., 2020) (Watson, Muhanad, & Hatamleh, 2014).

Architecture

In this area, we find different techniques for applications in architecture such as the traditional construction of cantilevered walls, in which an expert mason positions rows of bricks to achieve a curved effect on the wall without it taking over, also for this technique the expert modifies the bricks by carving them by hand (Stevens, Kamath, & Sharma, 2017). On the other hand, the ability to manufacture casting molds in various techniques such as the manufacture of plaster ornaments (Marshall, 2007), lattice modules in concrete (Karanastasi, et al., 2013), and prefabricated ferrocement (Peinovich & Fernandez, 2012). As well as manual skills for the construction of tessellations, or geometric compositions (Marshall, 2007) (Karanastasi, et al., 2013), and knowledge of the material to achieve an adequate mix of components.

Regarding the intervention with digital technologies in the case of the cantilever wall, the researchers, after observing the traditional technique and empathizing with expert masons, managed to take part of the tacit knowledge of the masters to build a parametric CAD model that guides the construction of a wall similar to the one built conventionally, also with a 3-axis CNC machine they carved the bricks, resembling the traditional carving they do in the conventional technique (Stevens, Kamath, & Sharma, 2017). About the other three techniques, their technological intervention was also given by observation and exploration with craft-based processes, and they focused on developing molds designed in CAD software and prototyped in laser cutting machines (Marshall, 2007) (Karanastasi, et al. , 2013).

Carving

In this area we identify techniques that are similar to manual skills for carving and sculpting material, we find two related to wood, for carving traditional bowls or plates (Grimshaw, 2017), and carving ornaments in traditional Italian furniture (Cianfanelli, Goretti, & Tufarelli, 2019), and clay carving for large-format sculptures, in addition, in this technique a small-scale model is first made, which is then scaled to a large format that exceeds one meter in height. height, skill, and experience of the sculptor are necessary for this task (Aleman, Meier, Perez, & Garcia, 2021).

We found different ways for the digitalization of the technique, for carving wooden bowls the researcher analyzed the process regarding the behavior and properties of the material, to define cut parameters in a CNC machine imitating manual labor (Grimshaw, 2017). In traditional furniture, researchers used reverse engineering with 3D scanners to obtain a bank of digital reference models of wood carvings, and thus safeguard the knowledge embedded in the objects (Cianfanelli, Goretti, & Tufarelli, 2019), and in large-format sculpting, they propose scanning the sculptures on a small scale and using the digital model in CAD software to scale the size of the model, to build cross-sections of the piece that will be used as polyurethane foam cutting guides and form the sculpture from serial plans (Aleman, Meier, Perez, & Garcia, 2021).

Other case studies

We grouped techniques that did not belong to a specific area, we identified two craft-based processes, the traditional pottery of Stoke-on-Trent United Kingdom, in which the researchers focused on the skills for the construction of molds (Echavarria, Weyrich, & Brownsword , Preserving ceramic industrial heritage through digital technologies, 2019), and for their digital intervention, they followed a strategy similar to that used in traditional furniture, the researchers used reverse engineering with a 3D scanner to obtain a bank of virtual models of the molds in order to safeguard the knowledge embedded in these artifacts since these objects have an important traditional value. The other case study deals with the traditional technique of 2D templates for dress pattern making, from the digital part the process was approached with 3D scanning of the body of the person who requires the dress, and from its digital model key points for construction were identified. of the templates from the digital model, this was done with the aim of making clothes that fit better to the size of each person.

Robots and automation

In this category we group the case studies that had as their objective, digital intervention, total automation of the technique without human intervention, directed by robotic arms that are programmed to carry out the manual activities of the workflow, emulating traditional techniques (Ravihandar , Polydoros, Chernova, & Billard, 2020). The purpose of this automation is to achieve more efficient processes (Phan, Kana, & Campolo, 2017), and the development of flexible manufacturing for mass customization and custom design (Trzepieciński, 2020). As in the previous group, the case studies were classified into common areas: Architecture, metal work, and other case studies, which are described below.

In the area of architecture, we identify research related to stonemasonry, on stone carving for architectural elements, in which it is necessary to have the ability to use the tools and make decisions regarding the way to carve the material since this it is not homogeneous (Shaked, Bar-Sinai, & Sprecher, 2021), (Shaked; Bar-Sinai; Sprecher, 2020). Similarly, the sand sculpture technique is in which special concrete blocks are prepared and carved with hand tools such as chisels and hammers (Kalo, Tracy, & Tam, 2020). On the other hand, the traditional adobe technique was found, which is a mixture of water, clay, sand, and organic fibers, in this work the material and its characteristics for the construction of walls were studied (Reyes, et al., 2019).

Another area of metalworking was also identified where we found study cases of traditional blacksmithing in which manual skill and experience with different tools, hammer, craft former, English wheel, and turning lathe for the manufacture of metal artifacts are shown (Russo B ., Cleaver, Allwood, & Loukaides, 2022) (Ilangovan, Monfared, & Jackson, 2016) (Rossi & Nicholas, 2018) (Bowen, Music, Erdinc, & Shokrani, 2021) (Russo, Cleaver, & Allwood, 2019) Similarly, we found a case study on manual skill in polishing metal parts (Kalt, Monfared, & Jackson, 2016). In addition, two particular case studies were identified on the skills for manual roughing of leather parts for shoe assembly, since it is an operation that requires great skill and experience on the part of the operator (Pedrocchi, Villagrossi, Cenat, & Tosatti , 2015). And this case the manual technique of manufacturing fiberglass molds requires dexterity and ability in decision-making during its operations (Kikuchi & Suzuki, 2016).

Regarding the digital adaptation of the techniques mentioned in the different areas, the researchers analyzed the body and manual gestures that the operator or technician performs when executing manual operations with movement recording tools as well as pressure sensors to measure force. of the elements with which they interact, this data serves as input to program or train the robotic arms that imitate the gestures of people, this process was repeated in all the analyzed cases of this group except for the traditional adobe technique in which a robotic arm was used for the trajectory of an extruder of the adobe material similar to 3D printing by the fused deposition technique (Reyes, et al., 2019).

Conclusion

We identify the characteristics of tacit knowledge that are used in several case studies to carry out a digitization of an artisanal process, in the form of 3 key attributes: Skills in the knowledge of the technique, corporal gestures and knowledge of the material and we show that the responsible integration of these attributes guarantees the reliability of the technique when intervened with digital technologies.

On the other hand, we find that despite the efforts of the investigations in the different case studies, not all the tacit knowledge of an artisanal process can be digitized, especially that which corresponds to the decision-making carried out by the expert in the different techniques. Workflow activities, as evidenced in the tests of robots that imitated the tasks of an artisanal process, only managed to carry out simple tests of the process, requiring greater efforts to achieve complete automation.

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