BUSINESSMEETSTECHNOLOGY

5TH INTERNATIONAL CONFERENCE

Universitat Politècnica de València, Spain
July 13th-15th, 2023

edUPV
Universitat Politècnica de València

Daniel Catalá Pérez
M Rosario Perelló-Marín
Conrado Carrascosa López (Eds.)

UNIVERSITAT POLITÈCNICA DE VALÈNCIA
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HOCHSCHULE ANSBACH

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BMT 2023 – 5th International Conference Business Meets Technology 2023

In 2023, we reached the 5th edition of the International Conference "Business meets Technology." This edition, held at the Universitat Politècnica de València with the support of the Faculty of Business Administration and the Department of Business Organization of this university, brought together more than 40 colleagues from different universities. Throughout the month of July 2023, we had the opportunity once again to share enriching sessions and collectively enjoy a comprehensive scientific and social program.

From a scientific perspective, a total of 30 papers were presented by approximately 70 authors who chose this event to share their research. The broad scope of this conference allows us to gather experts presenting the latest advances in engineering, as well as in the field of business management from various perspectives. It is increasingly common to encounter proposals also related to teaching innovation at BMT. In this edition, in addition, a novelty was introduced. Authors were given the option to choose the format in which they preferred their contributions to be published in this proceedings book: as an extended abstract, a traditional format in previous editions that allows authors to have their work assigned a DOI; and as a short abstract, enabling authors to participate in the conference by presenting the progress of their research without necessarily publishing a work that may still require further empirical or theoretical development. Nevertheless, the quality of all contributions has been a common characteristic of all the works.

From a social approach, BMT has allowed us to share moments that will always remain in our memory. We understand that in these types of events, informal networking moments can be the seed of future professional projects. At BMT, we know this well, and the collaboration projects shared between UPV and the University of Applied Sciences Ansbach are increasingly growing thanks to the close contact maintained between the two universities at the BMT and other common activities. Among the networking moments experienced during BMT 2023, we cannot overlook the different shared meals and the enjoyable team-building activity of cooking paella in the most traditional and pure Valencian style.

From UPV, we sincerely hope that we can continue to share with our colleagues from the University of Applied Sciences Ansbach and all those who wish to join, many more moments like those experienced during these five editions of BMT. For those of us who have been part of the organizing committee of BMT at UPV, the satisfaction of having created the conditions for this to be possible thus far has been immense. Therefore, regardless of what the future holds, we will always be ready to maintain the connections established.

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INFLUENCE OF CONTACT INTERFACE DESIGN OVER THE BOND FORMATION OF 3D PRINTED PARTS

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ABSTRACT: Fused Filament Fabrication (FFF) is an additive manufacturing technology that uses molten thermoplastic materials forced through a nozzle to build parts layer-wise and enables the manufacturing single and multiple materials parts. The multi-material interface bond strength influences the resulting part integrity. The interface represents the physical boundary between materials, and its shape depends on the part's design. However, the most common interface designs are based on a flat surface-to-surface contact. Thus, this paper aimed to investigate if the interface strength of polylactic acid-based (PLA) parts can be enhanced by designing new interface geometries with a sinusoidal and zig-zag pattern orientated in two directions. The resulting interfaces were tested mechanically and analyzed under the microscope to describe bond formation. The results show that interface shape orientation and overlap between mating bodies significantly influence the multi-material interface strength.

KEY WORDS: *3D Printing, Fused Filament Fabrication, Multi-material interface, Interfacial bonding, Bond strength.*

1. INTRODUCTION

Fused Filament Fabrication (FFF) is an extrusion-based additive manufacturing technology in which parts are built by selectively depositing a thermoplastic material (Gibson et al., 2021; Hasanov et al., 2021). To be deposited and maintain their extruded shape, the polymeric materials are heated and extruded in a viscous state in the form of filaments (Gibson et al., 2021) (often known as lines (Ghostkeeper, 2023)).

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The extruded lines are deposited on the previous or next to the adjacent lines creating intimate contact and developing interfaces. This contact between the deposited material and the other filaments is known as coalescence (Charlon et al., 2021; Lepoivere et al., 2021; Benarbia et al., 2023) and is influenced by the material rheological properties and the pressure exercised by the nozzle. As the material cools, the polymeric chains diffuse, creating molecular bonds and entanglements with the other filaments. This adhesion mechanism between the filaments characterizes the overall strength of the resulting parts (Watschke, 2018; Benarbia et al., 2023).

FFF enables the manufacturing of multi-material parts in a single printing process by using equipment capable of swapping the filaments or using one with multiple extrusion systems (Hazrat et al., 2021). The mechanical properties of the multi-material parts are given by the polymer's adhesion at the level of the Multi-Material Interface (MMI), the boundary between the parts. However, their chemical affinity limits molecular diffusion between different polymers (Watschke, 2018; García-Collado et al., 2022; Cunha et al., 2023). The contact interface area is crucial for multi-material parts made of compatible materials, as the MMI strength is obtained through diffusion (Lopes et al., 2019). For this reason, parts with reduced MMI area present low mechanical properties.

Several studies have been done to increase the bond strength between materials at the interface level by designing MMIs capable of increasing the intimate contact area between materials. Ando et al. (2021) studied the effect of inclined interfaces for tensile samples of PLA with side-by-side mating bodies. With an overlap between mating bodies, this solution increases MMI strength by creating vertical and horizontal contact areas. Frenkel et al., 2022 studied the performance of a woven interface to alternate the material layers for the same type of samples made of PETG and TPU. The results show that this MMI solution's strength is superior to the regular interface.

This paper aimed to study the effect of MMI design on mechanical properties and bond formation using different PLA blends. This way, the resulting interfaces were designed based on five parameters with defined values. Then the interfaces were printed as samples to evaluate the tensile and impact properties. Furthermore, the resulting MMIs were analyzed under the microscope to describe the bond formation.

2. METHODS

2.1 Design of experiment

The MMI interface designs were defined using five parameters with two levels of variation and organized based on a half-factorial experimental matrix (2^5). A sinusoidal and zig-zag pattern constrained by pitch (PP) and height (PH) was considered to improve the bond formation at the MMI level by increasing the contact area between layers. The pattern directions were orientated based on two directions, the y, and the z-axis. On the one hand, using the y-axis orientation, the resulting patterns will increase the vertical contact area between layers. On the other hand, the orientation of the pattern on the z-axis increases the area of horizontal contact between the stacked layers. An overlap between

multi-material parts bodies was considered to increase the bond formation between layers and compensate for extrusion inconsistencies (Ermolai et al., 2021). The chosen levels for each of the presented variables are presented in Table 1.

Table 1. Experimental matrix of the half factorial experimental plan (25) and the result obtained at the tensile and Charpy impact test, where σ represents the stress, ε the strain, and acU is the impact strength.

Run	Pattern	Direction	PP. (mm)	PH. (mm)	Ovp. (µm)	Avg. σ (MPa)	Avg. ε (%)	Avg. a_{cU} (kJ/m^2)
R1	sin	y	0.8	04	0	29.57±0.27	3.56±0.15	4.45±0.54
R2	zig-zag	z	1.6	0.4	100	25.07±1.10	2.79±0.17	4.50±0.46
R3	sin	y	0.8	0.6	100	29.81±0.67	3.68±0.14	6.40±0.67
R4	zig-zag	z	1.6	0.6	0	13.50±0.40	1.44±0.05	4.85±0.60
R5	sin	z	0.8	0.4	100	18.67±3.19	1.93±0.38	4.39±0.97
R6	zig-zag	y	1.6	0.4	0	27.12±0.34	3.14±0.05	4.96±0.76
R7	sin	z	0.8	0.6	0	28.65±1.14	3.34±0.21	4.17±1.33
R8	zig-zag	y	1.6	0.6	100	29.53±0.66	3.54±0.14	6.31±0.28
R9	zig-zag	z	0.8	0.4	0	18.96±2.02	2.01±0.22	5.04±0.62
R10	sin	y	1.6	0.4	100	27.44±0.37	3.08±0.06	6.35±0.47
R11	zig-zag	z	0.8	0.6	100	27.95±0.70	3.30±0.17	5.10±0.22
R12	sin	y	1.6	0.6	0	27.27±0.51	3.05±0.08	6.49±0.90
R13	zig-zag	y	0.8	0.4	100	25.08±0.96	3.16±0.16	3.50±0.32
R14	sin	z	1.6	0.4	0	10.29±0.94	1.08±0.09	3.52±1.40
R15	zig-zag	y	0.8	0.6	0	25.90±1.12	3.29±0.09	3.01±0.53
R16	sin	z	1.6	0.6	100	27.76±0.70	3.21±0.11	3.43±0.87
				Regular Interface (RI)		19.28±0.75	1.63±0.08	3.65±0.49w

The resulting interface configurations were printed as samples. For the tensile testing, the MMIs were designed based on specimen 1B of ISO 527-2 (Figure 1) and impact testing based on specimen 1 of ISO 172-1. A preview of the resulting MMIs designed by respecting the variables described in Table 1 is presented below. To better understand how the chosen parameters influence the bond formation, supplementary samples were printed for optical analysis of the MMIs for each configuration of variables in Table 1.

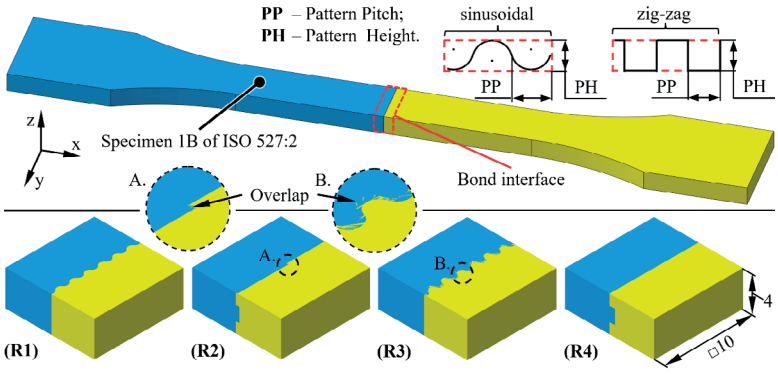

Figure 1. Multi-material interface design of the tensile samples. The resulting interfaces for R1-R4 variables configuration of Table 1.

2.2 Samples' manufacturing and preparation

All samples were printed on a BCN 3D Sigma X R19 using two PLA blends, blue and yellow, manufactured by BCN 3D using the main parameters described in Table 2. Five replicates were printed for each run covered in the experimental plan for the tensile test, ten samples for the Charpy impact test, and two for the optical analysis of the MMIs bond formation.

Wall ordering and *Alternate mesh removal* are two parameters that significantly influence the printing process of the MMIs. If we look at the contact interfaces of the mating bodies described in Figure 1, it can be observed that the external side surfaces of the mating bodies define the MMI. In FFF, the surface of a part is created through a filament (commonly known as a wall or perimeter). The *wall ordering* was set from *Inside to outside* for this experimental setup (Table 2). This way, the inner walls are deposited first (i.e., three walls) and then followed by the outer wall. As the adjacent deposited walls support the molten material, the *Inside to outside* printing sequence could increase material fuse at the MMI level.

Alternate mesh removal is a parameter available in Cura in the *Mesh fixe*s tab. By activating this parameter, the slicer removes a volume of one of the part bodies to make a place for the mating body. This way, a woven structure is created at the MMI level consisting of horizontal and vertical adhesion areas at the level of each layer (Mihalache et al., 2022). The horizontal adhesion area can be further extended by overlapping the part's mating bodies.

Table 2. FFF printing process parameters for BCN Cura 3.2.

	Process parameters	Value		Process parameters	Value
1	Layer thickness (mm)	0.2	13	Printing temperature (°C)	210
2	Extrusion width (mm)	0.4	14	Bed temperature (°C)	60
3	Inner wall extrusion width (mm)	0.38	15	Printing speed (mm/s)	45
4	Number of walls	4	16	First layer printing speed	20
5	Seam alignment on x (mm)	75/-75	17	Print jerk (mm/s)	20
6	Seam alignment on y (mm)	10/-10	18	Outer wall jerk (mm/s)	5
7	Walls ordering	Inside to outside	19	Fan speed (%)	90
			20	Regular fan speed at layer	3
8	Number of top/bottom layers	5	21	Brim width (mm)	6
9	Top/Bottom layers pattern	Lines	22	Purge tower size (mm)	25x25
10	Top/W	40/135	23	Merged meshes overlap (mm)	0
11	Infill pattern	Grid	24	Alternate mesh removal	Active
12	Infill density (%)	50	Italic values are associated with the left-side extruder.		

The samples for optical analysis have a 10x10 mm cross-section and the same thickness of 4 mm as the mechanical trials' samples (Figure 2). Surface preparation consisted of grounding the samples with a Strues Labo Force 100 machine in several steps to obtain a mirror-gloss surface finish. Abrasive papers with grits of 180, 500, 1000, 2000, and

4000 were used. All operations were carried out in the presence of a water jet to avoid warping or melting the workpiece. Finally, the polishing was carried out with a solution of abrasive particles with a diameter of 3 µm. The samples which describe the MMIs' xy plane were ground up to 2 mm, and those for the xz plane up to 5 mm (Figure 3-7).

The mechanical tests were carried out in the same laboratory conditions, in an environment having a temperature of 22°C and 55% humidity. Tensile tests were performed using an Instron 4411 uniaxial testing machine with a load capacity of 5kN. The impact strength was determined using a Zwick 5102.21 Charpy test machine using a 2J pendulum.

The optical analysis was carried out to characterize layers bonding at the interface level. The MMI analysis was performed using a Keyence Vhx 7000 digital microscope.

3. RESULT AND DISCUSSION

3.1 Mechanical strength

Overall, the tensile test results, presented as bar plots in Figure 2, show that compared to the Regular Interface (RI), the newly designed interfaces recorded improved tensile properties in stress and strain.

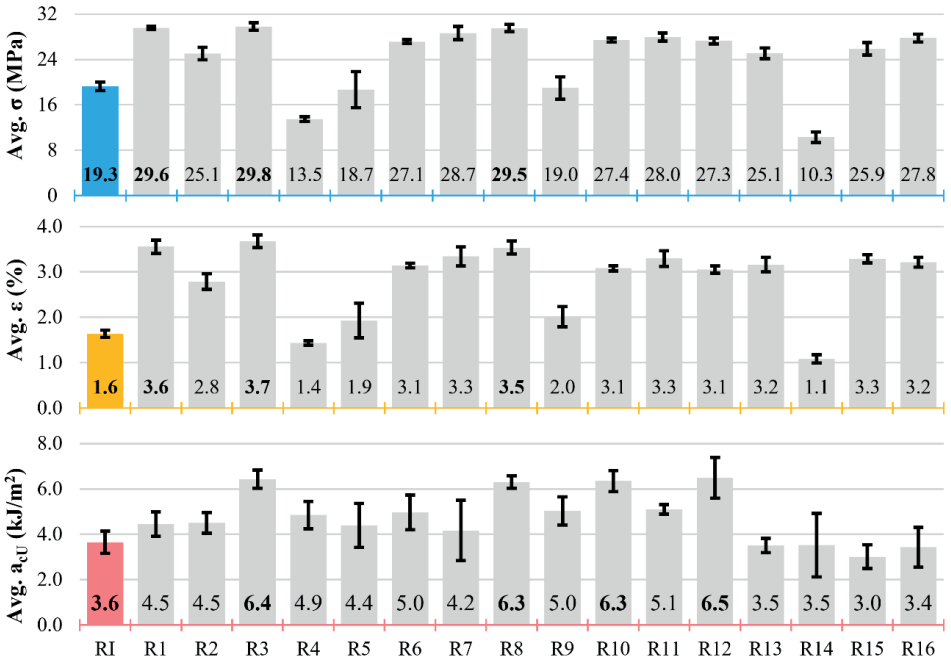

Figure 2. Average stress, strain, and impact strength of the MMI configurations of Table 1 compared to the RI.

From the 16 tested MMI configurations, the best results were obtained by the y-axis orientation of the patterns. The R1, R2, and R3 obtained the highest load capacities, showing an average stress above 29.5 MPa and an average strain above 3.5% (Table 1). Compared to the RI, the R1, R2, and R3 MMI show an increase of ≈53% in stress and ≈118% in strain. Withal, MMI designs such as R4 and R14 recorded stress and stain values lower than RI. These MMIs are characterized by the z-axis orientation of the profile and without overlap between the mating bodies (Table 1).

The Charpy impact test results were obtained for unnotched samples with a flatwise orientation. Overall, samples with a sinusoidal pattern orientated on the y-axis recorded the highest impact energy absorption. R3, R8, and R12 MMI configurations showed an impact strength of over 6.3 kJ/m^2 (see Table 1 and Figure 2). Those results represent an increase of ≈75% in impact energy absorption compared to the RI. The R10 MMI obtained comparable results with a zig-zag pattern on the same y-axis orientation.

3.2 Bonding analysis

Figure 3 shows the structure of a regular multi-material interface. As can be seen, the *Alternate mesh removal* parameter positively influences the formation of vertical and horizontal bonds between materials by creating an alternating deposition.

The front view of the part (Figure 3b) shows an alternating deposition of the two materials at the interface. In the same representation, it can be seen that the degree of alternation is inconsistent both in the top-bottom and left-right directions. At the base layers, the degree of alternation is higher (290-421 µm), and as new layers are deposited, the degree of alternation decreases, reaching a minimum in the middle zone (71-81 µm) and then increases again towards the upper layers (156-180 µm). This pattern was observed for all MMI analyzed.

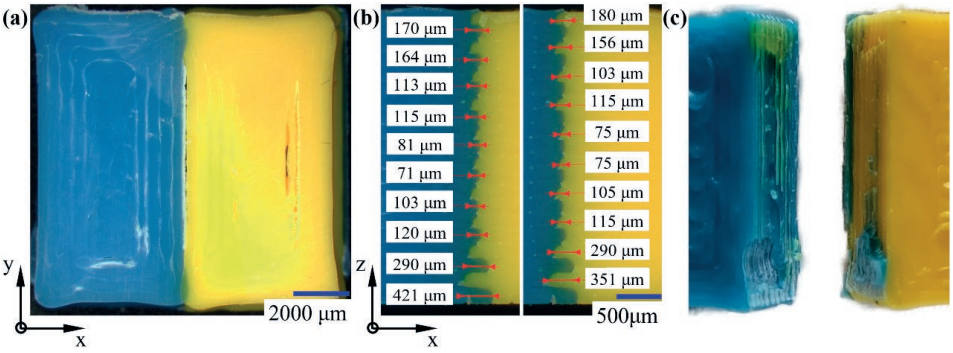

Figure 3. Internal structure of the RI (a) top view; (b) front view; (c) MMI failure mode at tensile test.

In the top view of the same part (Figure 3a), a partial bond of the two materials can be seen on the sample's extremities (green color areas). In the central area of the RI, a void between the materials was observed and can be correlated with the 71-81 µm alternation in the adjacent view (Figure 3b). The identified void in any of the printed samples can explain the poor mechanical properties of the RI (Table 1). From Figure 3c, it can be observed that RI has a poor adhesion of the samples' bodies. The fracture respects the RI profile, and the resulting pieces present traces of the mating material.

Figure 4 shows the internal structure of the R1 MMI (Table 1). The two materials' deposition path follows the interface's sinusoidal shape. Even though the degree of overlap between parts' bodies is zero, both views of the MMI show a smaller variation in alternation between layers. Except for the base layers (first three), which have an alternation of 667-825 µm, the layers show an alternation of 411-492 µm (Figure 4a), increasing slightly for the top layers. From the top view, it can be seen that changing the geometry of the MMI void formation reduced. Instead, a clear bond between materials can be observed (the green color sinusoidal line from Figure 4a). The effect of the improved horizontal bonding can also be seen in the breaking mode of the MMIs (Figure 4c). The fracture respects the pattern's sinusoidal shape but is located on the blue material side.

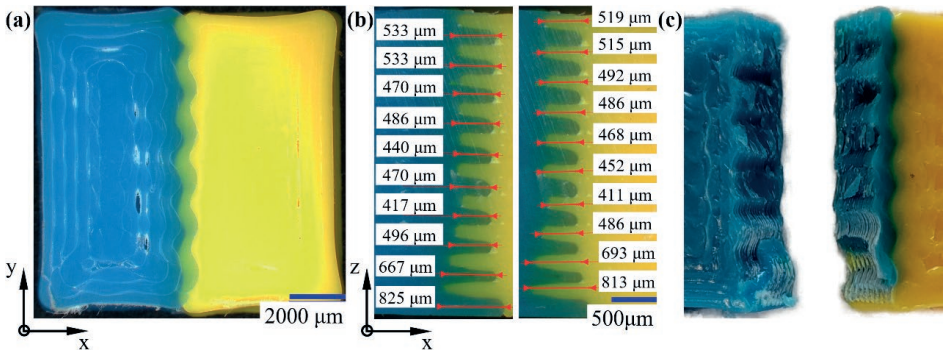

Figure 4. Internal structure of the R1 MMI (a) top view; (b) front view; (c) MMI failure mode at tensile test.

Figure 5 shows the structure of the R2 interface with a zig-zag pattern in the z-direction with 100 µm overlap between the bodies. The alternation between layers shown in the front view maintains the same pattern of variation as previously presented samples. Even though the samples' bodies were printed in superposition, the alternation degree is comparable with the R1 sample (without overlap). On the other hand, comparing the part with a similar zig-zag pattern without overlapping (see Figure 7), we observe that the parts' bodies overlap increases the horizontal contact area between the layers and, therefore, the mechanical properties (Table 1). Even with the increased horizontal contact area, the samples fail at the MMIs level (Figure 5c).

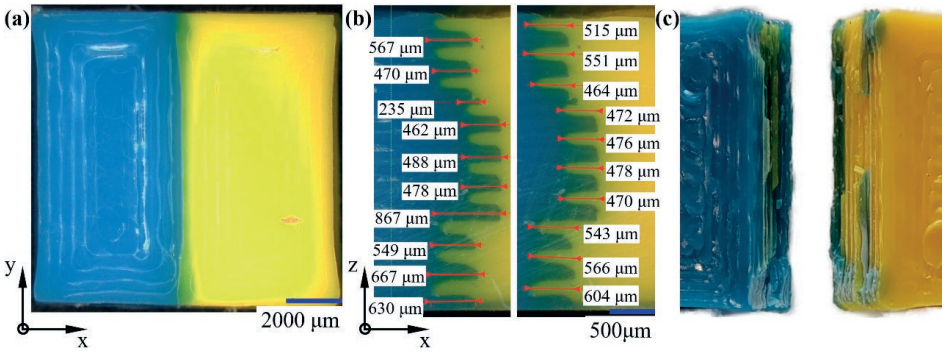

Figure 5. Internal structure of the R2 MMI (a) top view; (b) front view; (c) MMI failure mode at tensile test.

Figure 6 shows an MMI specific to the R3 configuration of parameters, with a sinusoidal profile oriented along the y-axis and a 100 µm overlap between bodies (Table 1). In contrast to the part with the same MMI pattern and direction in Figure 4, the resulting layers alternation is about 100 µm larger (Figure 6b), a value that coincides with the overlap. The increase in the horizontal bond area can be seen in the top view of the MMI (Figure 6a). From a mechanical perspective, the parts with the R3 parameter configuration obtained the best results in the tensile tests (Table 1). Samples failure partially respects the sinusoidal pattern. Due to the increased horizontal contact between layers, the fractures of R3 samples appeared in the body of the blue material at a distance of 1-2 material lines from the midplane (Figure 6c).

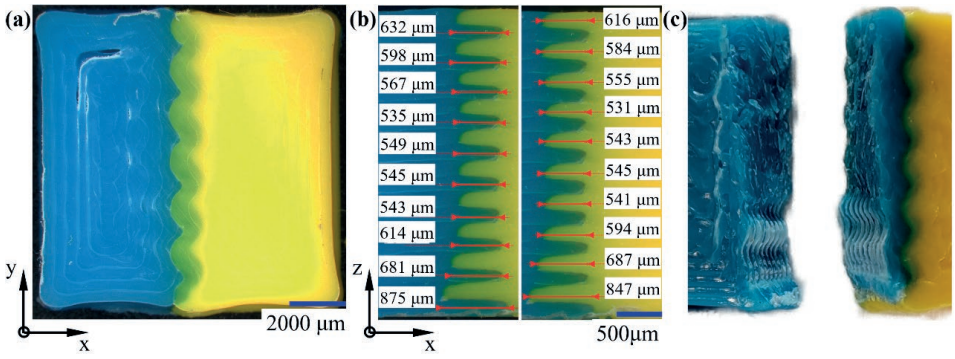

Figure 6. Internal structure of the R3 MMI (a) top view; (b) front view; (c) MMI failure mode at tensile test.

The R4 interface in Figure 7 is described by a zig-zag pattern with vertical orientation and no overlap between parts' bodies. The front view of the part shows that the alternation degree between the materials at the interface level is, on average ≈350 µm (except for

the base layers). This value is ≈100 µm smaller than there resulting horizontal bond areas of the R2 MMIs, with a similar pattern and 100 µm overlap. The small contact area between materials at the interface explains the poor results of the R4 MMI obtained in the mechanical tests (see Table 1 and Figure 2). Regarding the failure of R4 samples, from the example presented in Figure 7c, it can be observed that the absence of the overlap leads to a detachment of the MMIs layers with fewer traces of the mating material compared to R2 samples.

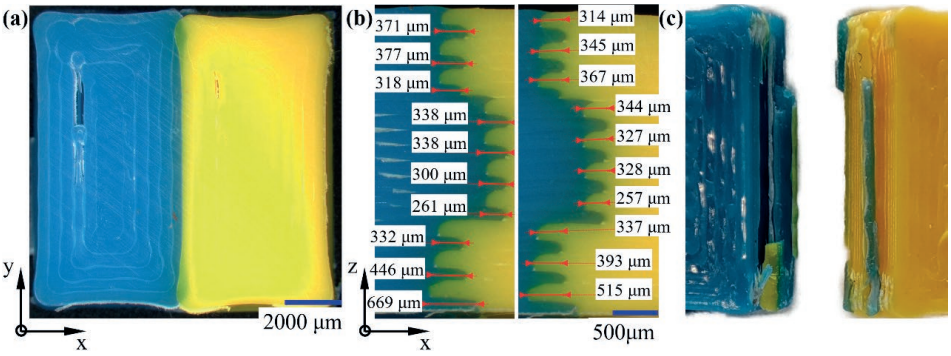

Figure 7. Internal structure of the R4 MMI (a) top view; (b) front view; (c) MMI failure mode at tensile test.

The variable degree of layer alternation at the MMI level can be explained by the filament cooling and solidification and the instantaneous speed of the extrusion systems during deposition.

3.3 Discussion

First, it can be observed that all analyzed MMIs show a higher degree of alternation at the base layers. This effect is caused by the FFF process parameter: *Regular fan speed after layer*, set at 3 (Table 2). This way, the cooling fan will start at the beginning of the fourth layer. During deposition, the first three layers solidify more slowly. Thus, the shrinkage of the material during solidification is smaller. This corresponds to the measured values. In the case of the first layer, the alternation is significantly higher due to the heat released by the build plate at the temperature of 60°C, a value close to the PLA glass transition temperature.

In the case of FFF, the instantaneous speed (often named Jerk (Ghostkeeper, 2023)) at the change of direction is always greater than zero, and its maximum value depends on the equipment. Otherwise, the material, which is constantly fed, overflows and affects the quality of the part. Thus, when changing the direction of travel for the outer wall, the travel speed of the extrusion system decreases to 5 mm/s, then returns to the normal deposition speed of 45 mm/s for the 10 mm width of the MMI, then decreases again

to 5 mm/s, to change the direction of travel again, followed by another return to the initial speed. As the material is in a viscous, semi-liquid state, it can be "pulled" by the printing head and thus deviate from the deposition path. The filaments' shrinkage can amplify this effect during solidification. These assumptions can explain the decrease in the horizontal contact area of R2 and R4 MMIs.

The effects described above are insignificant for parts with the profile arranged along the y-axis. Because the pattern is characterized by frequent direction changes, the print head travels the entire interface at the instantaneous speed of 5 mm/s. This way, the print head movements do not influence the deposition and bonding mechanism.

4. CONCLUSIONS

Multi-material FFF has introduced new possibilities for part manufacturing, allowing for multiple materials in the same components. However, further research is needed in order to improve the strength of the resulting multi-material interfaces.

Modifying the contact interface shape and providing an alternated deposition between the specimen bodies improved the mechanical properties of PLA-printed samples. Compared to the regular but-join interfaces, it was possible to obtain an increase of ≈53% for stress and ≈118% for strain at the tensile tests and an improvement of ≈75% in impact energy absorption for three of the MMIs designs.

The considered interface pattern and orientations help identify that regardless of the considered pattern, orientating it on the y-axis direction is the most beneficial for the strength of the parts. However, the features must be assisted by an overlap between the mating bodies and an alternated deposition at the interface level to increase the horizontal adhesion between layers.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

E.V. conceived, designed, and performed experiments, analyzed the results, and wrote the manuscript. S.A. and N.G. analyzed the experiments and technical proof of results and reviewed the manuscript. All authors have read and agreed to the published version of the manuscript.

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SHORT FORAY INTO THE STAGES OF CONVERSION FROM 2.5D TO VOLUMETRIC PRINTING

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ABSTRACT: Additive manufacturing gained popularity in the 2000s and is now considered a new or emerging technology of the 21st century. However, the origin of the process is much older and has existed for several decades, more precisely since the 20th century, when it appeared in small science fiction novels. In addition to these layer-by-layer approaches, there are also additive tomographic or volumetric approaches that allow the 3D object to be printed in a single step. These approaches are not so popular and consequently not fully understood or utilised. Thus, the paper briefly outlines the history of the transition from classical 2.5D printing, to 3D or non-planar printing, to 4D printing (with smart materials), to 5D printing (on equipment with more than three degrees of freedom), to 6D printing (a combination of 4D and 5D printing) and finally to volumetric and tomographic printing. The future perspectives of this technology are briefly presented with some applications and examples.

KEY WORDS: *2.5D printing, 4D printing, 5D printing, 6D printing, volumetric printing, tomographic printing, 3D objects, review.*

1. INTRODUCTION

According to various reports in 2022 (Ritchie & Roser, 2022; Organisation for Economic Co-operation and Development [OECD], 2022) global annual plastics production increased from two million tonnes in 1950 to 360.5 million tonnes in 2018 and respectively 459.75 million tonnes in 2019. According to assessments by the European Environment Agency (EEA) and the European Commission, global

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annual plastic production is expected to further increase by up to 1.2 billion tonnes by 2050 (European Environment Agency [EEA], 2019; European Commission, 2020). The dependence on these products is also reflected in the value of the global plastics market, estimated at 593 billion USD in 2021 (Statista Research Department [SRD], 2023) and 609.01 billion USD in 2021 (Grand View Research [GVR], 2022). By 2030, growth is estimated to reach 824.46 billion USD, with a CAGR (Compound Annual Growth Rate) of 3.98 % (SRD, 2023; GVR, 2022).

High annual consumption is due to the transformation of plastics into a wide range of products using primary manufacturing technologies such as injection (accounted of the largest market share of over 43.38 % in 2022 (GRV, 2022)) and extrusion moulding. In comparison, additive manufacturing is mostly used in prototyping application and less widely in industry. Other processing technologies, namely extrusion, atomization, sputtering, grinding, centrifugal disintegration, electronic deposition, calendaring, crushing, and chemical reactions are required to produce the raw material for additives processes (Fraunhofer, 2023). The most common forms of these raw materials are filaments, powders, rods, sheets, plates, foils, gels, pastes, liquids and fibres. Thus, similar to thermoforming (Throne, 2008), additive manufacturing can be considered a secondary processing technology.

Even so, a 2019 study shows that the global 3D printing market was estimated at 12.1 billion USD (SRD, 2020) and 15.2 billion USD in 2021 (Valuates, 2022) with a 25 % year-on-year growth from 2014 to 2019 (Jemghili et al., 2021). Due to a CAGR of 21.6 % from 2023 to 2033, the global additive manufacturing market size is estimated to reach between 76.16 and 77.83 billion USD by 2030 (Persistence, 2023; Strategic, 2021). This estimate includes revenues from 3D printing systems (equipment), software, materials, accessories, and services. 3D printing is one of the fundamental elements of the latest industrial revolution, known as Industry 4.0 (Jemghili et al., 2021).

In the literature, a number of papers can be identified that show the connection and transition from 3D to 4D (Zhou et al., 2015; Mallakpour et al., 2021), nonplanar approach (Nayyeri et al., 2022; Nisja et al., 2021), 5D printing (Anas et al., 2022), 6D printing (Georgantzinos et al., 2021), transition from 3D to 6D printing (Vasiliadis et al., 2022), volumetric 3D printing (Rodríguez-Pombo et al., 222). Yet, none of these provides a complete overview of the history of additive manufacturing and the stages of the transition from an idea in a fiction novel to volumetric printing.

Therefore, in the following chapters a brief review of the transition from 2.5 to volumetric printing as well as a brief overview of the history of additive manufacturing is given.

2. TRANSITION FROM 2.5D PRINTING TO VOLUMETRIC PRINTING

2.1 Short history of additive manufacturing

Additive Manufacturing (AM) is also known by other, more or less common names, such as 3D printing, Rapid Manufacturing, Rapid Prototyping or Rapid Tooling, Digital Manufacturing, Digital Fabrication or Desktop Manufacturing and Layered Manufacturing. Unlike the formative and subtractive approaches, the common characteristic of additive manufacturing processes is the formation of a three-dimensional solid object by depositing material or binder in successive layers until the desired final shape is obtained.

Based on a partnership agreement between ISO/TC261 (Additive Manufacturing) and ASTM Committee F42 (Additive Manufacturing Technologies), a common set of rules, classification and information on additive manufacturing has been created. Hence, based on the revised standard ISO/ASTM52900-2021 (Additive manufacturing - General principles – Fundamentals and vocabulary), the different 3D printing processes can be grouped into seven categories: Material Extrusion (ME), VAT Photopolymerisation, Binder Jetting (BJ), Material Jetting (MJ), Powder Bed Fusion (PBF), Directed Energy Deposition (DED) and Sheet Lamination (SL) (ISO/ASTM52900, 2021).

Long before this collaboration, Blanther J.E., Birdseye S.H. and Tyler M.C. (1956) proposed a manual method (Blanther, 1892) as well as an apparatus (Birdseye & Tyler, 1956) for producing topographic maps with three-dimensional graphics using a layering method.

Meanwhile additive manufacturing was just an imaginary technology in small science fiction novels. In the 1945s and 1950s, the science fiction authors Murray Leinster (in the short story "Things Pass By") and Raymond F. Jones (in the work "Tools of the Trade") described a fictional but similar manufacturing technology to the concept of 3D printing (Haines, 2022; McIntosh, 2022). Murray Leinster (1945) describes a robotic arm capable of taking his 2D designs and using molten plastic to create 3D models and Raymon Jones calls his technology Molecular Spray (Historydraft, 2023). Only 26 years later, Johannes F. Gottwald is granted the right for patent US3596285A- *Liquid metal recorder* (Gottwald, 1969), the application originally filed on 11/07/1969. He envisioned a device like a normal desktop printer but printing 3D objects from molten metal rather than printing ink text on a page.

Starting from this point, a long series of papers has been published in the literature, and new equipment, materials, patents or ideas ensued, as follows:

- The first attempt to create solid objects using photopolymers and a laser was made in the late 1960s at the Battelle Memorial Institute (Mouzakis, 2018). The experiment aimed to polymerize a liquid resin by intersecting two laser beams of different wavelengths in the middle of a tank;
- In 1968, based on a similar dual laser beam approach, Wyn K. Swainson of Denmark applied for a patent for his invention, entitled "Method of Producing a three-dimensional figure by *Holography*" (Swainson, 1968);

- In October 1974, David E.H. Jones (under the pseudonym Daedalus) published a satirical article jokingly describing a single UV laser curing process (Daedalus, 1974) in an article in the New Scientist. Dr. Adrian Bowyer (future founder of the RepRap movement) later stated that Daedalus had jokingly invented what we now call stereolithography SLA;

- Clyde O. Brown, Edward M. Breinan, Bernard H. Kear, as part of Raytheon Technologies Corp. (U.S.A.), filed an application for a patent entitled "*Method for fabricating articles by sequential layer deposition*" (Brown et al., 1979) on 29 November 1979. The rights to patent US4323756A are given on 6 April 1982 and contain information for the use of hundreds or thousands of layers of metal powder and a laser energy source to fabricate a 3D object on a substrate acting as a base or printing plate. Also, in the late 1970s, Dynell Electronics Corp. (New York, USA) was awarded several patents for making *3D solid photographs*. The method involves cutting cross-sections of plywood (using CNC equipment, a conventional milling machine or a laser) and stacking them to form the 3D object (Dariah, 2023);

- In April 1980, Dr. Hideo Kodama of the Municipal Industrial Research Institute in Nagoya, Japan, describes the first layer-by-layer approach called by himself *rapid prototyping*. In 1981, he received the rights for the XYZ plotter patent (Kodama, 1981c) and published a series of papers in which he described the fabrication of three-dimensional objects from thermoset polymer (photo-sensitive resin/photo-polymers) by preferential solidification using a UV light source and a pattern acting as a mask or a scanning fibre transmitter (Kodama, 1981a; Kodama, 1981b; McIntosh, 2022).

- The patent "Pulsed droplet ejecting system" (Zoltan, 1970) of the inventor Steven I. Zoltan published in 1972 and the patent US4336544A - "Method and apparatus for *drop-on-demand ink jet printing*" (Donald et al., 1980) would form the basis for the development and refinement of *3D material-jet printers* in the coming years.

- In July 1984, American entrepreneur and engineer William Edward Masters applied for a patent describing his computer automated manufacturing process and system- US 4665492A (Masters, 1984). In the years that followed he was granted over 40 more patents of which the most important are US 5134569A- "System and method for computer automated manufacturing using fluent material" (Masters, 1989a) and US 5216616A- "System and method for computer automated manufacture with reduced object shape distortion" (Masters, 1989b). In July of the same year, Alain Le Mehaute, Olivier de Witte and Jean Claude André filed an application to patent the *stereolithography* process (FR 2567668A1- "Dispositif pour réaliser un modèle de pièce industrielle"; André et al., 1984) in which they used UV light to cure photopolymers. Similar to the earlier cases of Gottwald J. F. and Kodama H., the ideas and patents of the three French inventors were abandoned or expired due to lack of interest from the public or the companies they were working for and lack of any significant commercial potential. At the same time, three weeks later, in 1984, 'Chuck' Hull

filed his own patent for stereolithography and also described elements such as the STL file and the digital slicing/stratification approach (Hull, 1984). His contributions form the basis of modern additive manufacturing technologies. Thirty years after 3D Systems (a company founded by Charles Hulls) kick-started the additive manufacturing industry with its SLA-1 equipment, it was declared a landmark in mechanical engineering by the American Society of Mechanical Engineers- ASME (ASME, 2016).

- In 1986, Carl R. Deckard filed a patent (Deckard, 1986) for an additive technology in which he replaced UV light with a beam of light from a laser to draw and solidify successive layers of powdered polymers (a technology known today as *Selective Laser Sintering SLS)*;
- Precision Optical Manufacturing, Inc. has revolutionized the field of additive manufacturing by developing *Direct Metal Deposition- DMD* (Dutta et al., 2011), a laser beam metal powder coating process used in the production and repair of three-dimensional parts;
- In 1989, Steven Scott Crump patented the *Fused Deposition Modeling FDM* process, introduced Prodigy, a machine that produces ABS components (Crump, 1989; Haines, 2022) and together with his wife (Lisa Crump) founded Stratasys Ltd.;
- On 04/08/1992, R. Helinski was granted the patent US5136515A (Helinski, 1989), which describes the method of fabricating a 3D object layer-by-layer by droplet-by-droplet deposition and heat solidification of two materials (base material for the main component and the second one as a support);
- In 1993, Soligen Technologies, Inc. (Texas, U.S.A.) began marketing a *Direct Shell Production Casting- DSPC* equipment (Soligen, 2023) used to manufacture ceramic moulds or shells (alumina, silicon carbide, aluminium oxide, etc.). Z Corp. launches the Z402 3D printer which is based on a 2D inkjet printer but uses powdered materials (starch and gypsum based) and a water-based binder to print 3D objects (technology known today as *Binder Jetting- BJ*) (Masaeli, 2012);
- In the mid-90s, new technologies such as *SDM- Shape Deposition Manufacturing* or *Microcasting* (Amon et al., 1998), *Mold SDM* and *SSD- Spray Shape Deposition* (Beck et al., 1992) were developed at Stanford University (California, USA) and Carnegie Mellon (Pittsburgh, USA) (Masaeli, 2012; Merz et al., 1994);
- In 1995, German scientists at the Fraunhofer Institute (Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V.) began the development of a technology (DE19649865C1) for fusing thin layers of metal powders using a high-power laser beam in an inert gas atmosphere (Meiners, 1996);
- In 1996, Dr Behrokh Khoshnevis patented *CC- Contour Crafting*, one of his ideas to use large printing layers to make huge parts (aircraft engines, sand moulds, etc.) on an industrial scale (Henke et al., 2016; Khoshnevis, 2006);

- In 1997, the AeroMet company developed the additive process with high-power lasers and titanium alloys in powder form called *Laser Additive Manufacturing LAM* (Ding et al., 2015; Wohlers & Gormet, 2015). During the same year the first manufacturer of *EBM (Electron Beam Melting)* 3D printers appeared (Markfoged, 2023) and used a stream of electrons guided by a magnetic field to melt successive layers of metal powders. Arcam AB (Mölndal, Sweden) developed *Direct Energy Deposition- DED* technology at Sandia National Laboratories, with equipment marketed by Optomec (New Mexico, USA) (Kumar, 2021). Although the operating principle is similar, diverse other variations of the process can be found under different names (Treutler & Wesling, 2021): *EBAM- Electron Beam Additive Manufacturing* (Sciaky Inc., USA), *LENS- Laser Engineered Net Shaping* (Optomec, Inc., New Mexico, USA), RPD- Rapid Plasma Deposition (Norsk Titanium AS Inc., Norway) or *WAAM- Wire Arc Additive Manufacturing*, *CMT- Cold Metal Transfer* (Fronius GmbH, Austria);
- WAAM has its origins as far back as the 1920s', thus making it the oldest additive technology (Dash et al., 2023; Twi, 2023) when R. Baker proposed to manufacture metal ornaments by using an electric arc as heat source and metal wire as base material. The WAAM technique can also be divided (Binato et al., 2018; Northeastern University [NU], 2020) into *GMAW- Gas Metal Arc Welding* (Ding et al., 2011), *GTAW- Gas Tungsten Arc Welding* (Dickens et al., 1992) and *PAW- Plasma Arc Welding* (Spener et al., 1998), *SAW- Submerged Arc Welding* and *SkAW- Skeleton Arc Welding* (Treutler & Wesling, 2021);
- In 1999 scientists at the Wake Forest Institute for Regenerative Medicine [WFIRM] successfully implanted a human bladder (WFIRM, 2023). The synthetic structure was made using a 3D printer and then coated with cells from the patient's own tissue to reduce the risk of the body rejecting the new organ. Three years, later they 3D printed a miniature human kidney. Although it was not full-size, this was a key advance in *3D bio-printing*, and later (in 2021) the institute received 2 awards in the NASA Vascular Tissue Challenge (WFIRM, 2023);
- In 2000, Objet Geometries Ltd. (Rehovot, Israel, later to become one of the Stratasys brands) announced the launch of the Quadra, an inkjet 3D printer that deposits and cures photopolymers using 1536 nozzles and a UV light source, giving birth to *PolyJet 3D printing* technology (Wohlers & Gormet, 2015);
- Dr. Behrokh Khoshnevis and his team at the University of Southern California develops the *Selective Inhibition Sintering- SIS* process of a metal, plastic or ceramic material without the use of a laser beam (Torabi et al., 2014; Khoshnevis et al., 2003);
- Since February 2004, a new revolution in the history of additive manufacturing has begun (Irwin et al., 2014), when Prof. Dr. Adrian Bowyer of the University of Bath, started an open initiative called RepRap (Replication Rapid Prototyper), offering free access to 3D printing to the general public. Another major consequence was the emergence of *Fused Filament Fabrication- FFF* technology;

- In 2008, the Thingiverse website, launched by MakerBot Industries, LLC, started to provide an easy way for the online community (home/private/independent makers and businesses) to access and use thousands of easily 3D printed models for free. It reached the top 700 most popular websites in the U.S. in 2021, hosting over 2.5 million 3D models today (Lind & Bertasius, 2023);
- In 2009, Scott Crump loses his patent for FDM technology and in 2014, the same happened to Carl Deckard's patent for SLS technology. In both cases, the doors were opening for many companies to expand by bringing equipment and materials to the market at much cheaper prices for independent users or companies. Thus, in January 2009 the BfB RapMan, the first affordable desktop 3D printer ($700 USD) is launched on the market, followed in April by the Cupcake CNC ($750 USD) of the much better known Makerbot brand (Kraft, 2009; Schneider, 2009);
- In 2011, KOR Ecologic produced the Urbee, the first hybrid car built using FDM technology (O'Neal, 2018) and Cornell University (U.S.) brought the first 3D printer for food manufacturing to public attention (Haines, 2022);
- In June 2012, five years after the original SLA patent expired, the B9Creator (Digital Light Processing- DLP printer) and Form 1 (SLA printer), the first two affordable 3D printers, were launched (Ouajjani, 2018);
- In 2013, Joseph and Philip DeSimone (from the Carbon® Company), inspired by the film Terminator 2 (Devlin, 2015), developed *Continuous Liquid Interface Production- CLIP* technology. Two years later, they announced the launch of revolutionary new printers (with print speeds up to 100 times faster than competitors' printers) that allow continuous printing of photopolymerizing resin objects. The new technology can be found today as *Carbon DLS*™ (*Carbon Digital Light Synthesis*™ (Carbon, 2023). Similarly, the company Nexa3D Inc. was developing and patenting (US20170129175A1) its own technology called *LSPc*®- Lubricant Sublayer Photocuring (Zitelli et al., 2015);
- In 2014, Dr. Benjamin S. Cook and Dr. Manos M. Tentzeris developed the first multi-material integrated printed electronics additive manufacturing platform *VIPRE* (*Vertical integration of inkjet-printed RF circuits and systems*) at the Georgia Institute of Technology, which enables functional 3D printing of electronic components for radio frequency communication systems operating up to 40 GHz (Stassen, 2014);
- In 2015-2016, two new innovations emerge in the medical field when CELLINK, as part of the BICO Group (Sweden) announces the first commercially available bio-ink material used in human tissue 3D printing and Trinity College Dublin [TCD] announces the printing of human bone or cartilage (TCD, 2016; Haines, 2022);

- In 2016, Hewlett-Packard Company- HP, began commercializing 3D printers with its patented *MJF- Multi Jet Fusion* technology (Kauppila, 2023). The company has also made its first foray into 3D binder metal printing with the *MJ- Metal Jet system*;
- Since 2016, the company Local Motors (Arizona, U.S.) has launched the first two 3D printed autonomous vehicles, named Olli, running on the Sacramento State University campus (Boissonneault, 2018). Their printing was made possible with the help of Thermwood company (Indiana, U.S.A.) and *Large Scale Additive Manufacturing- LSAM* technology (Aysha, 2020), the world's largest facility dedicated to additive manufacturing;
- In 2017, the first generation of FFF continuous belt printers (O'Connell, 2021) was launched with the release of Blackbelt 3D printer. Replacing the print bed capable of limited movement along the Z or X-Y axis with a belt capable of "infinite" movement (by continuously rotating it) and tilting the print head allows for an "infinite Z axis". In the same year, Prof. John Hart and Jamison Go, from MIT, succeeded in developing a dedicated *FastFFF* equipment that achieves a volumetric printing rate of up to 282 cm^3/h while conventional systems offer the possibility of printing at 10- 20 cm^3/h (Go & Hart, 2017);
- Over the period from 2016 to 2018, the use of 3D printers in civil construction became popular, materializing in the construction of artisanal structures, statues, bridges, houses and even some plans have been made for skyscrapers/office buildings in Dubai (Javelosa, 2017; Ramirez, 2020);
- Using SLM technology, Orbex, a UK spaceflight company, 3D printed a one-piece rocket on SLM 800 equipment (Davies, 2019). Similarly, Launcher Inc (California, USA) and AMCM GmbH (Additive Manufacturing Customized Machines, Starnberg, Germany), as part of the EOS GmbH group, have announced the successful production of a one-piece additively manufactured copper alloy liquid propellant rocket. The Engine-2 liquid rocket engine chamber was created on an AM4M M4K 3D printer (O`Neal, 2019);
- At the same time, additive manufacturing is already integrated into the U.S. Navy and Army supply chain (Metal, 2019; Suits, 2019) and in the production of five new warships for the Spanish Navy (Vialva, 2019).
- In 2020, due to the growing interest in metal printing, *Joule Printing*™ technology emerged and parts are made by melting a metal wire and depositing it in successive layers (Digital, 2023);
- In 2022, a manufacturing process patented by BCN3D, called *Viscous Lithography Manufacturing- VLM*™, enables the layer-by-layer production of 3D components by using a UV light and transparent films over which thin laminates of high-viscosity resin are deposited (BCN3D, 2022). In order to develop *Direct Sound Printing– DSP* a group of researchers, from Concordia University (Montreal, Canada) have moved away from classical approaches in which energy sources,

such as light and heat, are used to chemically or physically transform the polymers. The sono-chemiluminescence phenomenon, which underlies the technology, is utilized to create a hotspot (with high temperature and pressure) in cavitation bubbles directed into an enclosure containing a monomer (Habibi et al., 2022);

- On 24 March 2023, Northann Corp (California, USA) was granted a European patent for *DSE- Embossing Technology*. They use a combined positive and negative embossing method for 3D printing decorative panels/plates (Keane, 2023a). The same month also sees the release of AMULIT (Additive Manufacturing at Ultra-Low Interfacial Tension) technology, developed by a team of researchers at the University of Florida (Madeleine, 2023; Keane, 2023b). They use silicone-based elastomers, due to their biocompatibility and resistance (to heat, moisture and chemicals), in precise 3D printing of blood vessels (up to 4 μm in size) (Madeleine, 2023; Duraivel et al., 2023). In the same period but in the field of nanotechnology, researchers at the Chinese University of Hong Kong developed DH-TPL Digital Holography- based Two Photon Litography (Balena et al., 2023). This three-dimensional laser nanoprinting technology enables the fabrication of complex nano-sized structures at submicron resolution (Ouyang et al., 2023).

The latest research indicates a continuous development of the additive manufacturing industry not only through the development of new equipment dedicated to improve existing technologies but also through the emergence of new materials or 3D printing technologies. Thus, more than 75 (Boca et al., 2022) layer-by-layer or volumetric approaches (described in later chapters) for macroscopic and microscopic 3D printing can be identified.

2.2 Misconceptions related to the actual 3D printing

Although it is ingrained and used globally in a strict sense, 3D printing is in reality 2.5D printing (Gebhardt, 2003) because 2D layers or contours are made strictly in one plane (in most cases X- Y plane) and movement along the Z-axis is gradual, with a height corresponding to the height of the layer. Also, in a more simplified way the slicing software (CAM software required for all additive technologies) converts the 3D model into 2D layers along the transverse axis Z (Georgantzinos et al., 2021).

One way to take advantage of the Z-axis in conjunction with the X- and Y-axes is a technique called non-planar printing (Ahlers, 2018), Curved Layer Fused Deposition Modeling- CLFDM/CLFFF or non-horizontal printing (Chakraborty et al., 2008; Singamneni et al., 2012; Llewellyn-Jones et al., 2016), active-z printing (Khurana et al., 2017) and 'true 3D printing' (O'Connell, 2021).

One of the first papers addressing the aspects of the transition from flat to slightly curved layers is that of Chakraborty and collaborators in 2008. They use 3-axis CNC equipment dedicated to the FDM process in which the control method of the movements (printing table and printhead) is converted from *2C,P* (material deposition due to the movement along the X and Y axis and a point-by-point along the Z axis) to *2C,L* (similar

X and Y axis control but a linear interpolation control of the Z axis). They and Huang & Singamneni (2015) also recommend alternating the printing direction, for the upper curved layers, to reduce intrinsic porosity between layers and to increase isotropy of the continuous material string.

In 2012, Singamneni et al. presented research for the deposition of curved FDM printed ABS layers, for the fabrication of thin shell-shaped parts. Their CLFDM approach includes (Singamneni et al., 2012) the generation of surface points data using G&M code processing in a Computer Aided Manufacturing (CAM) module or through processing the part.stl file and subsequently, using of this point cloud data and an offsetting algorithm to generate curved layers. Two years, later Huang & Singamneni continue previous research focusing only on.stl file processing. They divide the FDM printed part domain into two distinct regions: adaptive curved layer on top and the flat layers at the bottom of the part. By using the mixed-layer approach (Huang & Singamneni, 2015), they obtained a scaled portion of an aircraft wing with improved surfaces and internal micro-structures and increased printing time compared to the classical flat-layer approach.

In 2016, Llewellyn-Jones et al. use an automated method for the generation of concave and convex layer to produce 3D printed components, such as vehicle body panel, shoe insole and dished sandwich panel. Similar to the previous cases, using a script written in MATLAB, they take the.stl file of the part and generate separate G-code files for each component (Llewellyn-Jones et al., 2016) of the printed part (e.g., scaffold structure which is printed with conventional static z layers and upon which the curved layer (buffer layers, or model skins) model will be printed using dynamic z-values). The difference is that they use and recommend a Delta printer instead of a Cartesian printer to combat speed differences along the X and Y axis versus the Z axis.

In the same year, Micali & Dornfeld (2016) come up with a different approach to the ones presented above. Their work also focuses on eliminating the stair-stepping artifacts in FFF technology on standard 3-axis equipment. To do so, they generate an inverse toolpath offset that can follow wavy/free surfaces and predict collision. Thus, the nozzle geometry also allows entrance into narrower regions, steeper inclines and a smoother surface due to nozzle sliding on the printed perimeters.

In 2017, Khurana et al., use active z-printing to get stiffer and stronger parts. They use (Khurana et al., 2017) two STL files (one for the main part and another with curved profile) and the open-source Bread slicing software (Parker, 2018) to generate the 3d printhead paths. They use a script in MATLAB to eliminate some of the problems (e.g. unnecessary travel movements that increased printing time and caused collisions) caused by the early stage of Bread slicer software development.

A major contribution to this non-planar printing took place in 2018, in Daniel Ahlers' master thesis from the University of Hamburg in Germany (Ahlers, 2018). The first step in achieving these curve profiles is to modify the FFF 3D printers to allow the print head to move freely up/down and right/left during material extrusion. Avoiding collision of the printing head components (nozzle, fans, air ducts, heating block, bed level sensor)

with existing printed sections can be achieved by using a longer hot end and/or a nozzle (Kupol, 2020) longer than conventional ones (the height of the outer cone is increased and its angle is reduced). Since active cooling of the printed raster is still required, the fans and air ducts must be readjusted. Ramírez-Gutiérrez et al (2020) propose even a unique adaptable base which brings advantages to the fabrication of curved-layered structures. It should be mentioned, however, that the printing is done using the 2.5D method to obtain a base and the first curved surface of the part (Ahlers, 2018; O'Connell, 2021). Therefore the stair-stepping effect is still to be expected. Only after that, the actual free printing on the previously obtained structure can begin. The second and equally important step is to generate the toolpath in the altered version of the Slic3r slicing software on Linux (O'Connell, 2021).

At the beginning of the process of creating collision-free nonplanar surfaces, information about the printer configuration (nozzle angle and the height of the printhead hardware) must be added, regardless of whether or not the printer has been modified. Since this entire project is public, all the information and files required are available online on the Github platform, under the name: Slic3r NonPlanar Slicing (Ebert, 2017).

Due to the open source nature of the project, all data can be used as is or modified as preferred. Some versions of the slicing software capable of non-planar printing for Windows have also been released due to the interest of some independent developers (Mbartlett, 2019). A similar phenomenon occurred with the introduction of the Creality CR-30 belt printer, also known as Naomi Wu's 3DPrintMill (Sink 2021). First launched as a Kickstarter project in November 2020 (Creality, 2021), the design of the 3d printer was created as a result of collaboration between Shenzhen Creality 3D Technology Co, Ltd. and three online community members.

In all the above papers and few others (McCaw & Cuan-Urquizo, 2018; Nisja et al., 2021), this printing method is available for 3-axis equipment dedicated to FFF/FDM technology. However, in the literature there is also a way to obtain curved layers using LOM technology. Klosterman et al. (1999) named the Curved Layer Laminated Object Manufacturing- CLLOM process and use materials such as monolithic ceramic and ceramic matrix composites to create shell-type objects.

2.3 How materials and equipment brought three new dimensions in additive manufacturing

The first way to implement a new dimension in 3D printing is through the materials selection rather than the equipment. Three-dimensional models are thus printed on regular 2.5D printers and designed to change shape, property and functionality over time. 4D printing is characterized by the ability of the parts to self-transformation, self-assembly (Tibbits & Cheung, 2012), self- sensing, self-adaptability (Khoo et al., 2015) or self-healing (Wang et al., 2018)/ self-regeneration. Shape changes manifest themselves through folding, expansion, shrinkage, twisting while self- healing through rebuilding of the polymer chains of the printed parts. Therefore, *time* is considered that the 4th dimension (Georgantzinos et al., 2021; González-Henríquez et al., 2019).

These so-called smart materials (SMs) or stimulus-responsive material (SRM) (Tzo et al., 2004) are able to respond in a reversible way to external stimuli variations (Roy & Gupta, 2003; Leist & Zhou, 2016) such as temperature, light, humidity, pressure, pH, magnetic field, electrical current, electrostatic interaction, solvents, Ca^{2+}, Mg^{2+}, radiation (UV and IR), ultrasound, etc. SMs can be classified into (Maheswari et al., 2022; Kamila 2013) piezoelectric materials, shape memory materials (SMM), magnetostrictive and magnetorheological materials, electrorheological fluids, chromoactive materials, optical fibres and photoactive materials. The most popular and common SMs in additive manufacturing are those with shape memory. These SMM can be divided (González-Henríquez et al., 2019), also, into shape memory alloy (SMA), polymer (SMP), hybrid (SMH), ceramic (SMC), gel (SMG) and of course, composite (SMc). Although SMPs first appeared in 1984 in Japan, they have experienced accelerated growth and increased interest from the research community. By using laminate form polymers, by combining two polymeric materials or combining the resulting polymer matrix with additive material, multiple controllable and reversible shape changes (Multi-Way Shape Memory Effects MW- SME or two way shape memory effects 2W- SME) can be achieved (Basit et al., 2013; Scalet, 2020). Due to the thorough design of the shape memory composition a dual shape changes or a response to multiple stimuli is enabled (Fu et al., 2018; Roy & Gupta, 2003). Dual-Stimuli-Sensitive Polymers can respond to a combination of stimuli such as light and temperature (Kurihara et al., 1998), pH and temperature (Gan et al., 2000), Ca^{2+} and acetonitrile or temperature.

Shape memory polymer blends typically (Kurahashi et al., 2012) consist of a network polymer containing physical or chemical crosslinks for the permanent phase, and the other amorphous or crystalline polymer playing the role of fixing the reversible/switching phase. In practice filaments such as Facilan™ PCL 100 Filament (3D4Makers, 2023) can be found on the market but it is more common to produce them. Such SMP blends are: polylactide PLA70/ thermoplastic poly(ether)urethane TPU30/CB (Qi et al., 2017), PLA85/poly(ether)urethane PU15/CB (Xiu et al., 2016), poly(ethylene vinyl acetate) EVA60/ poly(ε-caprolactone) PCL40/CNT (Zhang et al., 2016), poly(propylene carbonate) PPC70/PLA30/MWCNTs and PPC50/PLA50/MWCNTs (Qi et al., 2016), Poly(methyl methacrylate) PMMA/ poly(ethylene glycol) PEG (Liu et al., 2005), poly(vinyl chloride) PVC+PCL/TPU (Jeong et al., 2001) etc. The most popular nano-fillers (Ni et al., 2007; Mather et al., 2009) are carbon nanotubes (CNTs), carbon black (CB) nanoparticles, carbon nanofibers (CNFs), multiwalled carbon nanotubes (MWCNTs) but also nano-silica dioxide SiO_2 (Yan et al., 2013), silicon carbide (SiC) nano-particles (Gall et al., 2004) and magnetite (Fe_3O_4) (Razzaq et al., 2007) can be used.

In order to achieve dynamic rather than static structures, 4D printing diverges from classical printing (2.5D or non-planar) through the mandatory use of multi-materials, external stimulus and mathematical models and/or finite element analysis FEA (González-Henríquez et al., 2019). SMs multi-materials are the fundamental element underlying the change in shape because the differences in the materials physical properties. The stimuli provide the energy needed to trigger phase/morphological/structures changes and the mathematical model predict the changes in the final part. Such a mathematical model

and FEA is presented by Ge et al. (2014) and Mao et al., (2015), and serves as guidance for the selection of process and design parameters required for 4D prototyping. They use it to print flat polymer sheet with active composite hinges and apply it for self-assemble active origami structures (e.g. a box, a pyramid, and three or five hinge airplanes). With thoughtful design, multi-material assemblies capable of responding to different sensors can be achieved. One such example is the artificial insect controlled by multi-stimulus (magnetic waves, light and electric field) of Khare et al (2017).

The concept of *4D printing* was first introduced by Professor Skylar Tibbits (Founder and co-director of the Self-Assembly Lab at Massachusetts Institute of Technology- MIT) (Ly & Kim, 2017) in 2013. He initially worked with Stratasys Comp. to introduce two composite materials capable of changing shape when placed in water (one chain like object spelled MIT while the other morph into a wire frame cube).

Over time, this approach has been used in printing with electroactive polymers EAPs of dielectric elastomers or membrane actuators DEAs (Bar-Cohem, 2010; Rossiter et al., 2009) for soft-robots, printing of planar electronics that can electronically transform into nonplanar geometries at room temperature (Sundaram et al., 2017), 4D printing of SMPs self-interlocking components (Yu et al., 2015) which can react rapidly to a thermal stimulus and precisely change back the shape, 3D printing of piezoelectric device which can response to a finger-tap (Bodkhe et al., 2017; Chen et al., 2016), fabrication of parts able to mechanically (stretching, pressure) or chemically (pH) activate a chemical reaction which enable a colour change in the mechanochromic material (Peterson et al., 2015; Weder, 2011), smart valve able to respond to a hot/cold flow (Bakarich et al., 2015) or an acidic/basic flow (Nadgorny et al., 2016) proposed a 4D computed tomography approach which aim to reduce the exposure to radiation of patients, 4D food printing (Ghazal et al., 2022), 4D bio-printing of vascular endoprosthesis (stents) implant (Zhou et al., 2021; Wang et al., 2022a) and tracheal stent with thermal responsive material (Zarek et al. 2016), pH and thermosensitive medical device used for drug delivery (carrying and releasing) application (Gazzaniga et al., 2023; Sheikh et al., 2022).

The high interest in these applications is not only from the research community but also from companies and institutions such as (Reddy & Devi, 2018): U.S. Army Research Center, Stratasys, Ltd., Dassault Systemes S. A., NASA, Airbus SAS (France), Materialise NV, Massachusetts Institute of Technology, Hewlett-Packard, Inc., Briggs Automotive Company Ltd. (U.K.) and 3D Systems Corporation.

Unlike the non-planar approach and 4D printing, *5D or 5-axis printing* is more related to the type of movements the equipment can make. The method was first proposed by William Yerazunis, Ph.D., Senior Principal Research Scientist at Mitsubishi Electric Research Labs- [MERL] (Haleem & Javaid, 2019). The aim of this project was to obtain stronger components (on the whole surface of the part or where it is necessary), with a more complex design (including obtaining curved surfaces) and all this with a lower material consumption compared to traditional approaches. All this was achieved by adding two additional movements (rotations) of the printing platform of a FFF dedicated 3D printer.

Therefore, usually in addition to the three linear movements around the X- Y- Z-axis, a rotation A around the X and a rotation B around the Y-axis is also possible. These rotations make it possible to print curved layers more easily and without the need for or with a minimum amount of support structures (printing over an already printed surface can be facilitated considerably). At the same time, by using interwoven layers and eliminating the printing of flat layers, it is possible to obtain parts that are stronger (especially in the case of tensile forces with directions perpendicular to the printing direction), more aesthetic (with complex shapes and intricate geometries) and with reduced material consumption.

Similar to the configuration of conventional equipment and in the case of 5D printing, different approaches of displacements and rotations can be considered: either the printing platform is "fixed" and the print head performs the Z-axis displacement and the A and B rotations or the print head is "fixed" and the printing table (implicitly the printed part) rotates around the X and Y axis.

This technology is expected to bring new innovations and new users from dentistry (dental implants, crows, aligners, orthodontic braces and models) (Haleem & Javaid, 2019; Haleem et al., 2018), aerospace industry and medicine (surgical aids, gauges and implants) (Vshaper, 2023a).

Objects with steep overhangs can be printed (without the need of support structure) using multi-direction toolpath planning (Ahlers, 2018) or multi-axis material extrusion by curved layer slicing CLS (Kubalak et al., 2017). Such multi-direction slicing of CAD models were generated by Ding et al. (2015) for a five-axis robotic wire-feed additive manufacturing. The strategies presented in their study (volume decomposition and sub-volume regrouping) were implemented by programs written in Matlab.

Other algorithms capable of automatically slicing 3D models in multi-direction layers (without or with min. support structure and collision-free) for Layered Manufacturing technologies are: silhouette edge projection and offset slicing (concepts implemented in C++) (Singh & Dutta, 2001; Singh & Dutta, 2008), Multi-Orientational Deposition MOD algorithm (implemented using C++) (Yang et al., 2003), centroid axis computation (implemented in VC++ using and ACIS geometry kernel) (Ruan et al., 2006), normal marching algorithm (for 5 axis Laser Aided Manufacturing Process- LAMP) (Zhang & Lio, 2001), skin generation algorithm (Kubalak et al., 2017), skeleton method (for Laser-Based Direct Metal Deposition) (Eiamsa et al., 2001), adaptive spatial decomposition (enhance the performance of the centroidal axis method) (Ren et al., 2008) and adaptive slicing (for Hybrid Plasma Deposition and Milling- HPDM technology) (Xiangping et al., 2014).

In 2018, Ethereal Machines Halo, a 3D printer and milling machine that operates on 5-axes, received a CES award for the Best of Innovation Honoree in the category of 3D printing (Haleem et al., 2018). Other 5 axis hybrid printer on the market are 5AxisMaker's CNC (a desktop machine that offers both milling and 3D printing, launched on Kickstarter in 2014) (5AXISWORKS, 2023), CY1000 (robotic manufacturing cell for insulated wire

deposition, bare wire deposition, polymer deposition, printing of electronic components and pick and place operations) (Q5Technologies, 2023), 5AX Machine (5 axis industrial FFF printer with a rotary-tilt heated-vacuum- building platform, actively heated chamber and additional finishing and probing tool) (Vshaper, 2023b), University of Oslo's Pentarod 5 axis FFF printer (a modified version of the RepRap Ormerod, developed by a master student named Øyvind Kallevik Grutle) (Grutle, 2015) and Opex5x (an open-source project started by a team at Imperial College London, dedicated to converting the Prusa i3 3D printer into a 5-axis FFF printer) (Hog et al., 2022).

Still a domain waiting to be developed to its full potential, so far the only limitations of this technology are the extra cost of equipment (purchase, manufacturing, maintenance) and the need for skilled operators (Haleem & Javaid, 2019). W. Yerazunis stated in an interview that "5D printing does require a lot of analysis and it does require knowing how the part will be used. But when you can make a part that's five times stronger, that really changes how you think about 3D printed parts." (MERL, 2017).

As a natural next step in the evolution of additive manufacturing, the concepts of 4D and 5D printing are being combined into one, to take the advantages of both approaches. Georgantzinos et al. describe the idea of *6D printing* for the first time (Vasiliadis et al., 2022) in 2021 and refers to it as "a child born from the marriage between a five-axis printer of FDM technology and SMs" (Georgantzinos et al., 2021).

Since 4D printing is performed on conventional 3-axis printers, some of the limitations of the layer-by-layer planar approach are inherited by the resulting intelligent components. However, the addition of two additional degrees of freedom (specific to 5D printing) allows the manufacture of SMs components with more complex shapes the use of less raw material, shorter processing/printing time and increased structural integrity, flexibility in design and part functionality.

The printing method also allows the use of intelligent raw materials with nano-inclusions, nano-fillers and nano-reinforcements. These special composite materials (presented above, in the 4D section of this sub-chapter) already offer the possibility of obtaining parts with dual shape modifications. Due to the advantages of 5D printing and an optimal design, it is expected to manufacture SMs with the possibility of at least three shape transformations.

Involving smart materials into 6D printing, can lead to custom-made orthopedic casts that are capable of providing mechanical corrections of the arm or foot. There will be no need of weekly cast replacement because the smart material will change the shape over time, becoming tighter or looser according to the affected limb condition. As an example, the "smart cast" (Vasiliadis et al., 2022) can be a great solution for the most common congenital orthopedic foot deformity also known as clubfoot (Ganesan et al., 2017). By using this dual approach innovations will emerge in areas such as medicine (prosthetics, orthopedics, dental, custom-made implants) construction (pipes capable of changing their diameter and shape as a result of the introduction of a fluid), aerospace engineering, food sector and manufacturing.

Similar to 5D and 6D printing can be achieved by introducing more degrees of freedom at the detriment of using smart materials. By using this approach, the printer head has the ability to move around from six different angles or less, and the additional moves an rotation, at defined angles, are done by the mobile printing platform (including the printed part).

To achieve the required 6 degrees of freedom, modifying a conventional 3-axis printer can be an arduous, costly and time-consuming problem (ZHAW, 2016), which is why 6-axis CNCs or robotic arms and adapters for printing heads are preferred (e.g. Trumph 1000W CW laser and a coaxial powder head mounted on Kuba robot (Pinkerton, 2010) and 6- axis robotic-end effector and KUKA robot arm for ABS printing (Shi, 2014)). Especially, robotic arms have the benefits of speed, agility and flexibility in printing (Ding et al., 2015; Vasiliadis et al., 2022; Kubalak et al., 2018) and their control is already known before the advent of 3-, 5- or 6D printing concepts.

In practice (at industrial level) technologies such as Direct Metal Deposition DMD™, Laser Engineered Net Shaping LENS™, Laser Powder Fusion LPF™, AREVO polymer Directed Enerrgy Deposition DED, Continous Fiber Coextrusion CFC system are performed on 5 or 6-axis systems (with or without an additional rotary axis for the printing platform), and with the help of a 6-axis comprehensive CAM software (Dutta et al., 2011; Aero, 2023; Anisoprint, 2023). Such examples of printing systems are the DMD 105D/505D (5-axis equipment on CNC platform), DMD 44R/66R and DMD IC106 (6-axis industrial robot), LENS® 860 (rugged CNC platform with til-rotate printing platform), LENS 850R (5-axis gantry system coupled with a tilt-rotate platform), HP- 115 and HP- 205 (fully automated 5-axis powder deposition systems), AREVO® AQUA System (6-axis robotic arm), Anisoprint PROM PT (a 6-axis robot arm Continuous Carbon Fiber- CCF Printing system in development) etc.

2.4 Elimination of the layer-by-layer approach

The necessity to overcome the problems associated with the layer-by-layer approach led the scientific communities, along with some companies to develop new concepts, namely volumetric (holographic printing or multi-beam AM) (Rodríguez-Pombo et al., 2022) and tomographic printing. These new approaches allow the fabrication of macro-, mico- or nano- scale 3D components in a much shorter time by free deposition and/or dispensing of droplets or strands/ribbon of liquid/paste/ink material, (Parupelli & Desai, 2019) or by projecting a hologram, patterns or several laser beams inside an enclosure or VAT with photosensitive material. The first methods referring to the sequential manufacture of a product by direct deposition (Direct Writing DW) of material are presented below. Later new concepts emerge into volumetric and tomographic additive methods, which allowed parts to be produced “at once” (Hoeben, 2022), namely by selectively solidifying/ curing voxels (the 3D equivalent of a 2D pixel) (Kety, 2021) inside a vat filled with photosensitive resin.

Early means of rapidly manufacturing components:

- *Matrix Assisted Pulsed Laser Evaporation*-MAPLE DW: A pulsed laser is induced through a ribbon (double layer material made of a laser transparent material coated with a viscous material of interest/ink) to eject/transfer the ink onto the substrate (Piqué et al., 2003). Also, micro-machining is possible by allowing a direct interaction between the laser and the substrate) (Parupelli & Desai, 2019);
- *Laser Chemical Vapor Deposition* LCVD: A guided laser beam is used to induce a chemical reaction in a reactant in order to deposit thin films of various materials (metals, ceramics, insulators, semi-conductor etc.) on the surface of a substrate (Elliott, 1995). Three-dimensional parts can be obtained in two ways, depending on the mechanism that triggers the chemical reaction. Consequently LCVD technology can be separated into two categories, namely (Duty et al., 2001; Piqué & Christey, 2001) pyrolytic (thermal energy of the laser beam is used to heat the substrate surface to the temperature necessary to initiate the chemical reaction) and photolytic (photons from the laser beam are used to break the chemical bond within the reactant gas).
- *Dip-pen Nanolithography* DPN: is the first macroscopic DW- SPL (Scanning probe Lithography) technology involving the use of an atomic force microscopy mechanism to deposit molecular patterns (from certain inks, e.g. alkanethiols, biological molecules like DNA, viruses, and proteins, polymers, and nanoparticles) on the surface of a substrate (Krivoshapkina et al., 2016; Piner et al, 1999). Other variations of SPL technologies are 3D nanoprinting Atomic Force Microscopy AFM or AFM Nanolithography (Ventrici de Souza et al., 2018; Obermair et al., 2011), 3D nanoprinting Scanning Tunneling Microscopy STM (Liu et al., 2016; Plank et al., 2020), 3D nanoprinting Scanning Probe Microscopy SPM (Garcia, 2020; Dietrich et al., 2019), 3D nanoprinting Focused Electron Bean Induced Deposition 3D-FEBID (Seewald et al., 2022; Plank et al., 2019), electrochemical probe microscopy SEPM (Oswald et al., 2022), Fountain-pen Nanolithography FPL (Lewis et al., 1999; Kkim et al., 2005), Fluidic- Enhanced Molecular Transfer Operation FEMTO (Vengasandra et al., 2005), thermochemical Nanolithography TCNL (Szoszkiewicz et al., 2007), Polymer-Pen Lithgrophy PPL (Huang et al., 2010; Huo et al., 2008);
- *Solvent-Cast Direct Writing SC- DW*: being a method based on Direct Writing extrusion principle, the thermoplastic material is extruded through a nozzle and deposited on a substrate. The major difference between this technology and those presented above is that the base material is mixed with a evaporable solvent which allows the ink to solidify quickly (Balani et al., 2021). Thus it is possible to print parts without the need for a support structure for bone and tissue engineering (Dong et al., 2020; Omidia-Anarkoli et al., 2019), from PLA for Isotropic thin film fabrication (Singh et al., 2019), from and for intelligent materials applications

(Wan et al., 2019), polycaprolactone PCL based ink for biomedical and prosthesis applications (Camacho et al., 2019; Geisendorfer & Shah, 2019) and for electronic or electric applications (Hardin et al., 2019).

A new printing concept, developed by researchers at North Carolina State University, emerged in 2013 in the field of micro-component manufacturing called *Direct-Write 3D Liquid Metal- DW 3D LM* (Ladd et al., 2013a; Neumann & Dickey, 2020). In contrast to *Laser based Direct Writing- LDW* (Arnold et al., 2011; Schiele et al., 2010), manufacturing is carried out at room temperature and does not require auxiliary systems or laser sources to melt the metal. DW 3D LM enable the formation of stable structures (using a syringe) in a liquid medium due to the passive oxide layer/film (~1 nm thick) on the surface of the low-viscosity liquid metal (gallium alloy). Thus wires with a diameter of 270 μm and a height of 8 mm can be obtained as well as complex or free-standing shapes with a size ranging up to 10 μm (cylinders, 3D drop arrays, arcs, spheres, etc.) (Ladd et al, 2013b).

Both before and after, variations of direct printing with liquid metal has proven to be an effective method in various applications such as: printing of wireless wearable flexible microfluidic device (Koh et al., 2016) capable of capturing, measuring and storing quantitative values for sweat rate, total sweat loss and colorimetric readouts (pH, concentration of lactate, glucose, chloride and hydronium ions), epidermal heat flux sensors for continous noninvasive measurement of core body temperature, electronic skins e-skins (Wang et al., 2015) with liquid metal circuits- LMCs (Guo et al., 2018a) (wearable electrocardiogram ECG for physiological signals monitoring), omnidirectional printing of flexible, stretchable and spanning silver (silver nanoparticle ink) microelectrodes for electronic and optoelectronic devices (Ahn et al., 2009), multi-layer highly-stretchable strain sensors with integrated readout liquid metal paste circuitry (Votzke e tal., 2019), wireless wearable healthcare monitors (puls wave measurement) using directly-printed Ni-GaIn amalgams (Guo et al., 2018b), multylayer microstrip patch antenna (Hayes et al., 2012) (multilayer liquid eutectic gallium-indium- Ega-In encased in an elastomer), conformal printed hemispherical small antennas (tapered liquid silver meander line affixed to patterned cooper feed lines on a low-loss laminate substrate) (Adams et al., 2011), and many other flexible/stretchable wearable electronics (Lin et al., 2023; Bao et al., 2016; Gao et al., 2012; Boley et al., 2014).

Later, truer and more complex volumetric and tomographic technologies emerge on the market and between the research community. In 2017, as a result of the collaboration between MIT (MIT's Self-Assembly Lab) and Steelcase Inc. (Michigan, U.S.A.), a new process of rapid additive manufacturing in liquid/gel environment was born, named *RLP Rapid Liquid Printing* (Charbauski, 2023; Rapid, 2023). It is used to produce components (especially furniture parts) on a large scale ("with a large enough tank, the process can create objects of any size"- Simon-Lewis, 2017) with high precision, with quality industrial materials in minutes (Rapid, 2023). The major difference between classical additive manufacturing technologies and RLP (is that the part is produced in a liquid suspension (gel with the consistency of a hand sanitizer or hair gel) by direct

extrusion/injection of the material (plastic, metal, ceramic, elastic materials, etc.) to form composites rather than the classical layer-by-layer approach (Simon-Lewis, 2017; Hajash et al., 2017).

However, the technologies that are best known or have attracted the most attention are Readily3D S.A.'s 3D tomographic printing and Xolo3D's volumetric printing called Xolography. Emerged in 2017 and developed by researchers from the Ecole Polytechnique Fédérale de Lausanne (the future founders of Readily3D S.A.) the tomographic approach allows 3D photo-polymerization (using shaped light beams from multiple angle) for direct printing of a desired part. Simultaneous illumination of the entire building volume allows for build times in the order of seconds and parts as small as a few centimetres (Readily, 2023; Hoeben, 2022) without the need for support structures. Xolography or linear volumetric 3D printing (Regehly et al., 2020), originally developed in 2019, allows a material with photoswichable molecules, to be accurately solidified at the intersection of two light rays of different colours. The difference between this technology and conventional ones such as SLA/DLP/LCD is that the planar printing area is moved continuously and at speed inside a vat of material as opposed to the slow movement of material inside the tank followed by the exposure of layers (Kety, 2021).

Other volumetric, toographic and DW technologies available on the market or under development are: *Computed Axial Lithography* (University of California) (Kelly et al. 2019; Wang et al., 2022b), *Stanford 3D printing* (developed at Stanford University and Harvard University) (Sanders, 2022), *Ultrafast volumetric 3D bioprinting* (University Medical Center Ultrecht and École polytechnique fédérale de Lausanne) (Bernal et al., 2019), FluidForm's *FRESH™ 3D bioprinting* (Fluidform, 2022), *Scaffold-free 3D bioprinting* (University of Illinois at Chicago) (Jeon et al., 2019), *FabRx Volumetric printing system with DLP projector* (colaboration between University College London, University of Santiago de Compostela, MERLN Institute for Technology-Inspired Regenerative Medicine, and pharmaceutical 3D printing specialist FabRx Ltd.) (Rodríguez-Pombo et al., 2022), *micro-CAL* (Lawrence Livermore National Laboratory and University of California) (Toombs et al., 2022), *tomographic volumetric additive manufacturing* (Madrid-Wolf et al., 2022), *Continous Inkjet CJ- DW manufacturing process* (Desai & Lovell, 2012), *Aerosol Jet DW* (Rosker et al., 2020), *Digital Holography- based TPL- Two Photon Litography or Ultrafast 3D nanofabrication via digital holography* (Ouyang et al., 2023), *Two-Photon-Polymerization Direct Laser Writing TPP- DLW* (Gissibl et al., 2016), *Micropen by Exxelia* (Exxelia, 2023) and *Beam Based DW- Focused Ion Beam FIB* (Edinger, 2002).

3. CONCLUSION

In the present paper, a short review of AM techniques has been conducted, along with applications and materials specific to some of them. Since its origin, additive manufacturing has undergone an accelerated evolution from short stories in science

fiction novels or timid and unsuccessful attempt to create a three-dimensional object, to development of over 75 technologies, to being part of the latest industrial revolution, known as Industry 4.0.

The production and global market value of plastics has reached its peak in recent years and is expected to grow exponentially in the coming decades. Although injection moulding holds the largest market share (43.38% in 2022, followed by extrusion moulding) of plastics processing techniques, 3D printing is also growing with increasing interest from companies. As opposed to classical technologies, due to the low cost of equipment and materials dedicated to additive technologies, both the research community and independent/home/hobbyist users have come up with their own ideas and ways of improvement that have massively contributed to the growth and development of 3D printing (e.g. Creality CR-30 belt printer with "infinite X-axis", thousands of free 3D models ready to print on dedicated websites, non-planar printing, RepRap open source initiative etc.).

Although it is ingrained and used globally in a strict sense, 3D printing is in reality 2.5D printing, since the slicing software converts the 3D model into 2D layers along the transverse axis Z (hence the name layer-by-layer). Approaches that can benefit from all 3 axes are called 'true 3D printing', non-planar printing, Curved Layer Fused Deposition Modelling- CLFDM/CLFFF, non-horizontal printing and active-z printing. Such applications can be achieved by using a 3-axis CNC machine and converting the Z-axis point-to-point movements into linear movements either by using special algorithms designed to separate the part into individually sliced components, or by using CAM software capable of allowing planar slicing of the part followed by a non-planar coating of the upper surfaces.

Unlike non-planar printing, 4D printing with smart materials (especially shape memory material) received a huge interest from the research community and is used for a multitude of applications in different field. In many of these cases the actuation or shape change triggering is done without any additional equipment such as wires, batteries, or electric motors. In addition to components capable of transforming themselves in response to external stimuli, adding new dimensions to 3D printing is achieved using multi-axis equipment. This has resulted in 5D printing and, as a final evolution, 6D printing (which can also result from combining 5D and 4D printing).

The problems (high printing times, surface quality, structural integrity and mechanical properties) associated with the deposition of material or adhesives layer by layer associated with conventional printing can be overcome with the help of direct writing concepts and in particular by implementing volumetric or tomographic approaches. They allow the fabrication of components all-at-once by projecting a hologram, patterns or several laser beams inside an enclosure or VAT with photosensitive material or by free deposition and/or dispensing of droplets or strands/ribbon of liquid/paste/ink material.

Given the rapid developments and changing trends (increased interest in plastics followed by an increase in additive manufacturing methods with metallic materials, printing with smart materials, development of bioprinting, increasing sustainability of processes) over the years it is hard to predict what will happen to 3D printing or what form it will take in 10, 5 or even a year. Despite these advances, there are still some challenges to be overcome but it is clear that: 3D printing which started as a means of prototyping has become a tool for either mass production or for unique or customized products, new faster and more reliable equipment, materials and accessories will come onto the market, multi-dimensional printing will gain popularity due to the high levels of flexibility in design, efficiency and structural integrity of components, implementation in even more biomedical applications (manufacturing of stretchable-flexible-wearable medical devices and tissue deposition for organs printing) etc.

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INFLUENCE OF STORAGE CONDITIONS OF PVC ROOFTOP SHEETS ON THE HOT AIR WELDING PROCESS

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ABSTRACT: One of the common welding methods for polymer rooftop sheets is the overlap welding by hot air either done manually for small parts or with a welding machine for long sheets. The weld quality depends on different parameters like the welding speed, the welding temperature or the pressure applied on the joining materials. Due to the field of application of rooftop sheets, there are other environmental influences like the ambient temperature, the air humidity or direct sunshine which can cause a decrease of the welding quality. This work will focus on a pre welding influence, the storage temperature of the rooftop sheets and how it affects the welding quality. Two poly vinyl chloride (PVC) rooftop sheets were chosen and tested separately. The materials were cut into small sheets, stored under different temperature conditions, and were welded afterwards. The welded samples were tested according to the DIN EN 12317-2 to determine the shear resistance of the weld as it is an important mechanical property and a good indicator for the quality of the weld. The results show a minor influence on the welding process but no influence on the quality of the weld itself as all weld lines of all samples managed to stay intact.

KEY WORDS: *Hot air welding, PVC, rooftop sheets, welding conditions, welding quality.*

1. INTRODUCTION

Hot air welding has been proven to be an applicable welding technique for polymer parts, rooftop sheets or even for polymer-metal hybrid structures (Kobayashi et al., 2019). It can be separated in different welding techniques such as the tack welding, the permanent hot gas welding, or the high-speed welding (Rotheiser, 2009). This work will focus on another hot air welding technique, the overlap welding, as it is a common method for welding

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rooftop sheets. For this method a rooftop sheet is placed on top of another sheet with only a certain part overlapping and then a hot air fan, followed by a pressure roll is lead through the overlap (Oba et al., 1994). The surfaces of the sheets are melted and the pressure of the roll bonds them together. This welding method depends on some different parameters to achieve a good welding quality. The main parameters are the welding temperature, the welding speed and the pressure applied to the rooftop sheets. However, as the sheets are used to cover roofs outside, there are a lot of other influences on the weldability of the sheets and the quality of the weld itself, like rainfall during the welding process, direct sunlight, wind, or the humidity of the air (Bucko et al., 2012). Research has shown that the ambient temperature has an influence on the welding of ethylene vinyl acetate (EVA) rooftop sheets and welding parameters must be adapted to ensure a good weld quality (Park et al., 2020). Another influence on which this work focuses, is the effect of the storage temperatures of rooftop sheets. There is no common guideline as to how storing temperatures affect the welding since producers of rooftop sheets usually only recommend a dry storage.

2. METHODOLOGY

To analyze and characterize the effect of storing temperatures, PVC rooftop sheets are stored under different temperatures and welded directly after the temperature treatment. As there is a wide variety of different PVC rooftop sheets, two rooftop sheets were chosen. Material 1 is the Bauder Thermofol U15, a PVC-P rooftop sheet with polyether sulfone (PES) synthetic fibers insert and material 2 is the Wolfin IB a homogenic PVC-P rooftop sheet without fibers (Figure 1).

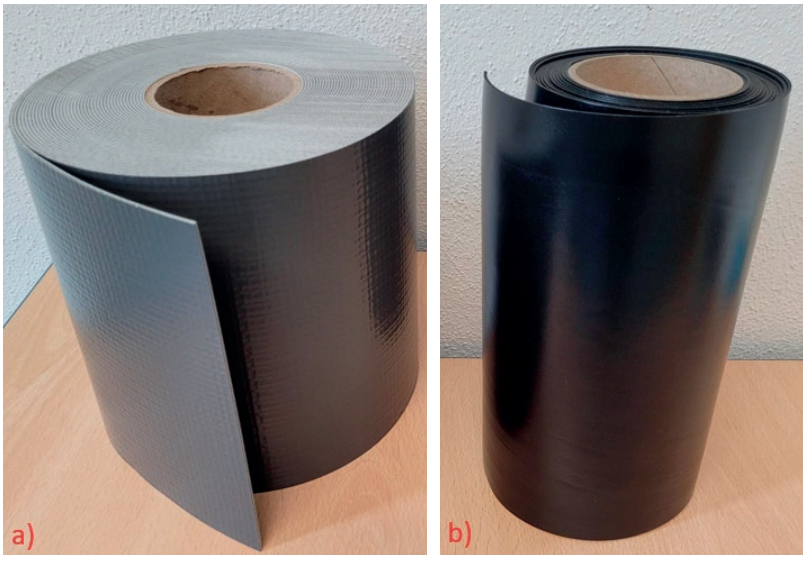

Figure 1. Rooftop sheets Bauder Thermofol U15 (a) and Wolfin IB (b).

Regarding the storage temperatures, five different temperatures were chosen: -18 °C, 0 °C, room temperature, 40 °C and 60 °C. These temperatures represent a wide range of possible storage temperatures which can occur depending on the way of storing the material and the given environmental influences. The materials were cut into two sheets, for each chosen temperature, with the dimensions of 200 mm × 200 mm and stored for 24 hours in the freezer, fridge, or oven. After the storing process the samples were taken out of the storing devices and immediately being welded by the hot air welding method. For the hot air welding method, a laboratory hot air welding machine was used (Figure 2).

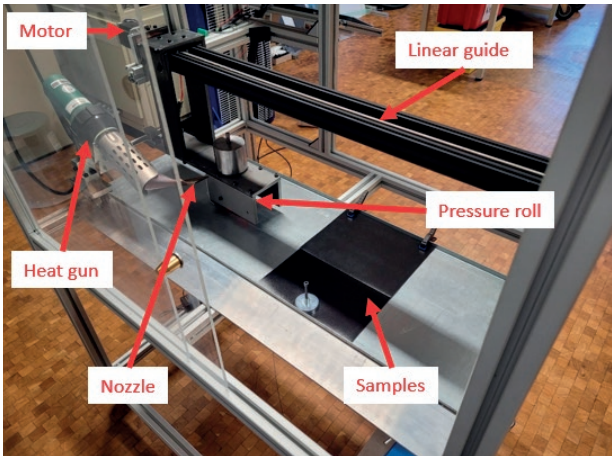

Figure 2. Laboratory hot air welding machine in the workshop of the University of Ansbach.

The device was developed and constructed at the University of Ansbach and is capable of welding small rooftop samples (Michalak, 2022), similar to rooftop welding machines. It is possible to set different parameters like speed, temperature, and pressure directly at the machine to ensure a consistent welding process. The chosen parameters for the welding are 500 °C for the welding temperature and 2.2 m/min for the welding speed. These values were within the recommended welding parameters for both materials according to the installation instructions and material datasheets. The recommended parameters for the welding of the Bauder Thermofol are in the range of 480 °C to 580 °C for the welding temperature and 2 m/min to 4.5 m/min for the welding speed (Bauder, 2020). For the Wolfin IB the recommended welding temperature is around 520 °C and the welding speed around 2.2 m/min (Wolfin, 2023). Regarding the pressure no additional weight was added as first welding tests have already shown a good weldability without added weights. After pre-heating the hot air fan of the device, the cut sheets were put into position and the welding process was started with the selected parameters. The hot air fan is guided through the contact surfaces of the materials, causing them to plasticize while the roll follows and applies the pressure to join them. After the welding process the materials were left cooling and then stored for 24 hours before being cut into 5 samples for each variant (Figure 3).

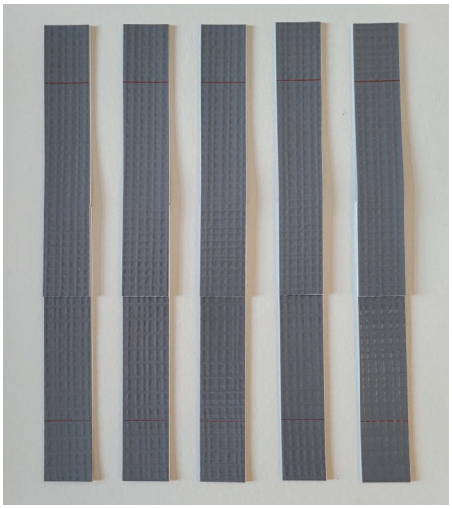

Figure 3. 5 samples for the tensile strength test of the material Bauder Thermofol U15.

The welded samples are tested according to the DIN EN 12317-2 (Deutsches Institut für Normung [DIN], 2010), with a minor change in sample dimensions, to determine the shear resistance of the weld as it is an important mechanical property and a good indicator for the quality of the weld. The samples prepared for the testing have a width of 25 mm instead of 50 mm as stated in DIN EN 12317-2. This change had to be done to ensure a proper fixation in the tensile testing machine as the clamps have a width of 25 mm as well. The tensile testing machine used for the determination of the shear resistance is the Instron 4411 with a 5kN load cell.

3. RESULTS

The results of the tensile strength test show different behaviors of the materials. The samples of the Bauder Thermofol U15 tend to break with two peaks in the tensile strength test (Figure 4).

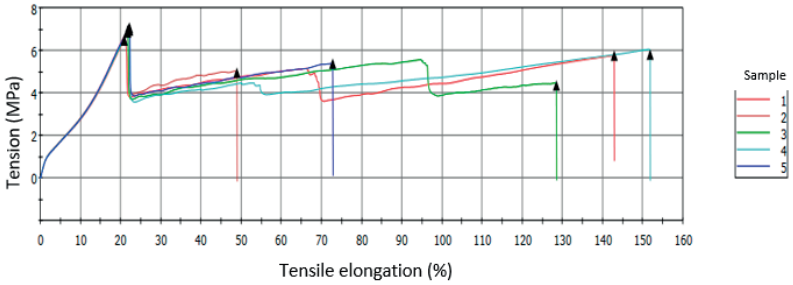

Figure 4. Results of the samples 1 till 5 of the Bauder Thermofol stored at room temperature.

The first peak shows the breakage of the fibers and the second peak the breakage of the PVC material. All the samples had similar first peaks, but the second ones were very dissimilar. This was caused by the preparation of the samples, as they were cut and the number of fibers can vary depending on the location of the cut, and by the influence of the tensile strength test when the fibers broke. In Figure 5 it is clearly visible in which parts the fiber and the material of the samples broke.

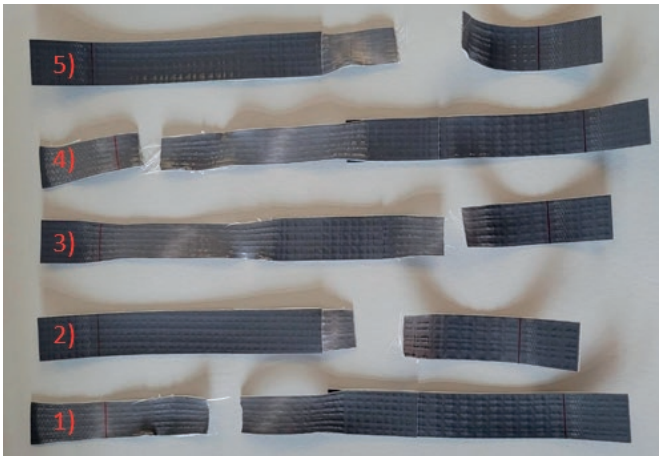

Figure 5. Samples of the Bauder Thermofol stored at room temperature after breakage.

However, the welded connection of all tested samples of every variant stayed intact, and every breakage took place above or below the welding. The force at the first peak causing the breakage of the fibers corresponds to the maximum force which was applied to the welding itself and the comparison of all five variants showed similar results (Figure 6).

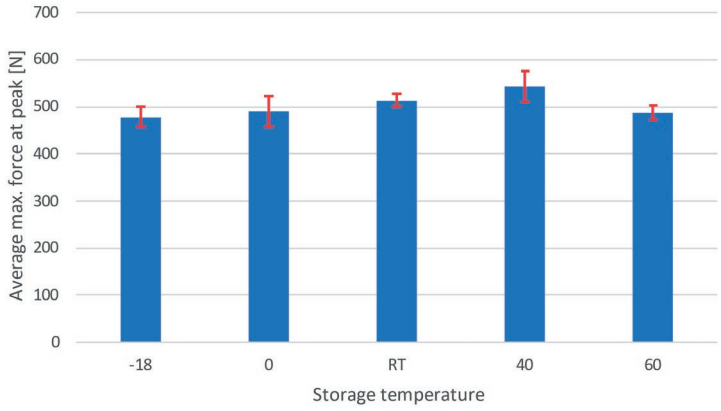

Figure 6. Maximum force at peak on all Bauder Thermofol samples of all variants.

The Wolfin IB material managed to not break in total and to use the maximum way for elongation of the tensile testing machine. The maximum force on the welding is the peak tensile strength at the maximum elongation of the tensile testing machine (Figure 7).

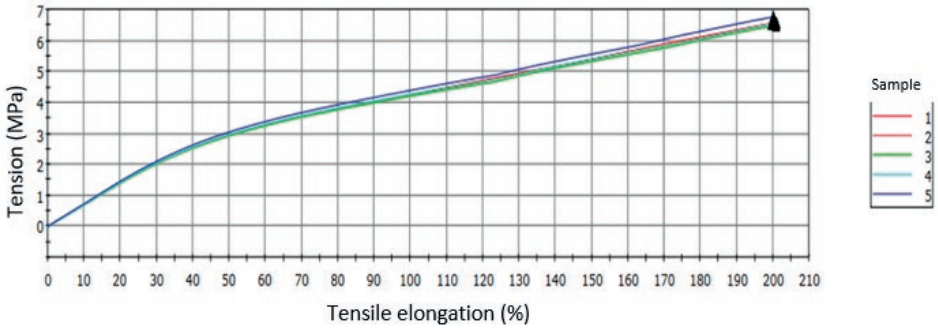

Figure 7. Results of the samples 1 till 5 of the Wolfin IB stored at room temperature.

The samples show an elastic behavior and shrink slowly back nearing their dimensions before the tensile strength test. A small deformation is visible in the area around the welding but there is no real damage to it (Figure 8).

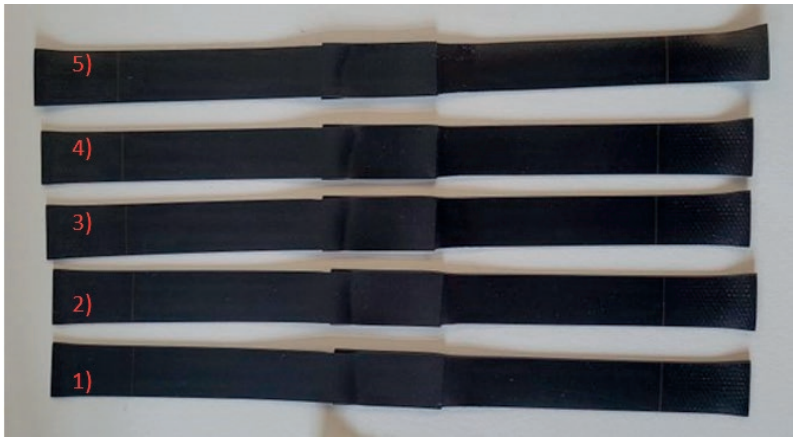

Figure 8. Samples of the Bauder Thermofol stored at room temperature after the tensile strength test.

The comparison of the maximum force on the welding of all the samples shows that they all are in a similar range (Figure 9) and have less deviation than the Bauder Thermofol samples, as it is just one material influencing the whole tensile strength test.

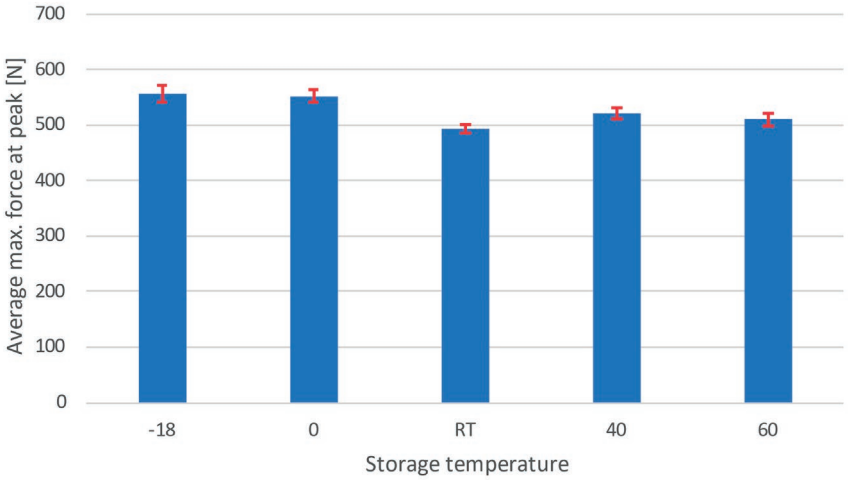

Figure 9. Maximum force at peak on all Wolfin IB samples of all variants.

4. CONCLUSION

Out of all 50 tested samples not a single weld line broke, which demonstrates a good weld quality of the samples no matter which way they had been stored before. The results of the tensile strength tests did not clearly indicate any influence of the storage temperature at all. If room temperature is considered to be the usual storing condition, there were no big deviations to the other variants. All weld lines of both materials managed to resist maximum forces of around 500 N. However, there were some influences on the whole welding process caused by the storage conditions of the materials due to changes in the stiffness of the material. This caused the material to be stiffer when stored in cold temperatures, or softer when stored in warm temperatures. While the stiffer material did not cause any trouble during the welding of the softer material was more difficult to be welded as the material was easily pushed away by the hot air fan running through the welding surfaces resulting in uneven weld lines. The material had to be separately fixed to avoid this failure pattern to appear. All in all, the influence of the storage temperatures between -18 °C and 60 °C on the welding process is so small, that it can be neglected. However, this can vary considering different materials and should be tested material specifically in further research of the influences of the hot air welding process.

CONFLICT OF INTERESTS

There is no conflict of interests.

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VIRTUAL NITROGEN OXIDE SENSOR FOR IMPROVED EMISSION CONTROL IN NATURAL GAS/HYDROGEN COGENERATION POWER PLANTS

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ABSTRACT: This study demonstrates the need for novel gas engine control systems for combined heat and power plants, also known as cogeneration power plants, connected to natural gas grids. Hydrogen addition to natural gas grids in a range of up to 5% by volume is already permitted throughout Europe. This offers the possibility to reduce carbon dioxide emissions of end consumers connected to public natural gas grids and contributes to climate protection. However, conventional engine controls are not designed for natural gas/hydrogen mixture operation. We tested fuels with up to 30% hydrogen by volume using a commercial six-cylinder spark ignition engine, designed for natural gas or biogas operation in power plants. With engine settings according to usual cogeneration operation, nitrogen oxide emissions increased exponentially with increasing hydrogen amounts. We demonstrate that the usual approach of using the lower heating value of the fuel mixture to regulate the engine is unable to accommodate the hydrogen induced changes. For this reason, we developed a mathematical model to determine the nitrogen oxide emissions based on boost pressure and power output. The idea behind this novel approach is to regulate the engine based on emissions, regardless of the fuel gas. In this work the approach for this virtual sensor is described and its performance demonstrated.

KEY WORDS: *Hydrogen; Virtual Sensor; CHP-unit; Natural Gas; Cogeneration.*

1. INTRODUCTION

The transition to a climate-neutral energy supply is a critical challenge facing society, as it has the potential to mitigate the impacts of climate change, reduce dependence on fossil fuels, and promote sustainable economic growth. One of the key challenges in achieving a climate-neutral energy supply is the storage of large amounts of green energy. Among the various energy carriers, hydrogen has emerged as a promising candidate due to its

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ability to store and convert back into electricity in large quantities relatively easily. As a result, the establishment of hydrogen storage and transport infrastructure is being planned in the European Union (Hydrogen Council, 2017).

However, the transition to a hydrogen-based energy system also presents a number of technical challenges, particularly in the context of existing natural gas grids. To reduce the carbon dioxide emissions of current natural gas consumers, hydrogen is intended to be injected into existing natural gas grids as intermediate step. However, the impact of this on consumers connected to the grid is still the subject of current research.

Focus of the present study are the challenges for natural gas engines in combined heat and power plants (CHP-units) that usually employ a control system to keep the lower heating value (LHV) of air/fuel mixture $h(\lambda)$ at a preset value. If a change in this value is registered, the system reacts by making the mixture richer or leaner (decrease or increase the equivalence ratio λ), ensuring that ideal engine running is guaranteed while complying with the legal exhaust gas limits (Zacharias, 2001). However, if hydrogen is part of an air/fuel mixture with an equivalence ratio λ according to the manufacturer's recommendation for pure natural gas, the air/fuel mixture can and must be made leaner in order to comply with the legal nitrogen oxide (NO_x) emission limits (Mehra et al., 2017; Yan et al., 2018).

The analysis reveals that the usual approach of using the lower heating value of the air/fuel mixture $h(\lambda)$ to adapt the equivalence ratio λ to different fuels is not suitable in case of hydrogen admixture. The LHV of hydrogen itself is lower that the LHV of natural gas, but the air demand for a complete combustion is also lower. Hence, an air/fuel mixture with a certain LHV corresponds to a certain equivalence ratio λ, independent of the hydrogen amount in the fuel. As a result, the faster and hotter burning hydrogen would cause exponentially rising NO_x-Emissions. To address this issue, a mathematical model to determine the nitrogen oxide emissions from boost pressure and power output is presented. This virtual sensor can be used as the key component of a novel mixture control system for natural gas engines in cogeneration power plants, which do not rely on the lower heating value of the air/fuel mixture.

2. EXPERIMENTAL SETUP

Figure 1 depicts the fuel supply system utilized in this study, which enables the engine to operate with mixtures of natural gas (NG) and hydrogen (H_2). The H_2 is obtained from bottles, whereas the NG is derived from the public grid and consists of 96% methane, 3% ethane, and 1% traces of other gases. Precise measurement of the flow rates and stepless mixing ratios of both gases are facilitated through separate mass flow controllers. The NG/H_2 fuel gas mixture is blended with air in a venturi gas mixer. The resultant fuel/air mixture is then compressed with a turbocharger, intercooled, and delivered to the engine through a throttle valve.

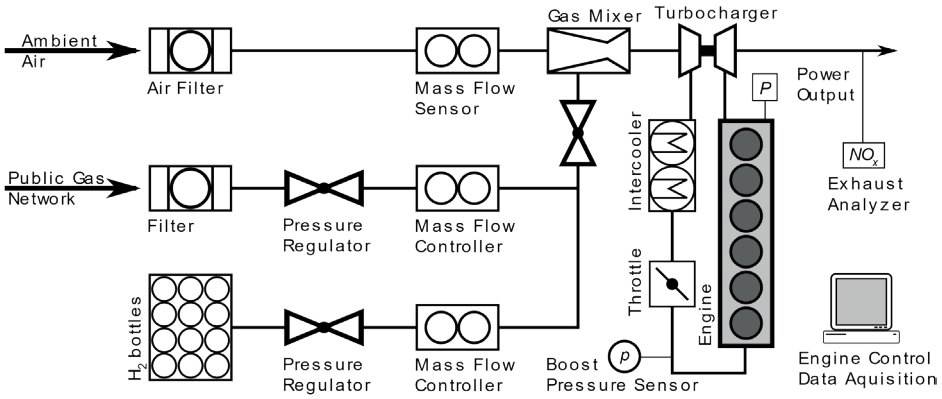

Figure 1. Schematic drawing of the engines fuel supply system.

The six-cylinder MAN engine used in this study was specifically designed for natural gas and biogas operation. The engine is controlled by self-developed software, which allows for the variation of engine parameters such as ignition timing, throttle valve position, and mixture control. Additionally, the software is able to record the values of all sensors installed at the engine test bench.

The input variables for the virtual sensor are the boost pressure and the output power. The boost pressure is measured after the throttle valve using a common pressure sensor, while the power output is calculated using the torque measured at the crankshaft and the engine speed.

To verify the calculated NO_x emissions, an MRU 'Vario plus' exhaust analyzer is employed.

3. RESULTS

3.1 Lower Heating Value of Hydrogen containing Fuels

The standard reference variable for gas engines in cogeneration power plants is the lower heating value (LHV) of the fuel gas mixture h(λ). If e.g., the methane content of the natural gas changes, the LHV of the air/fuel mixture also changes. However, substitution of natural gas with hydrogen within the currently allowed range in Europe (up to 5%) does not have an impact on the LHV (as shown in Figure 2), and therefore, conventional gas engine controls do not react and instead, keep the equivalence ratio λ constant. This poses a challenge as the nitrogen oxide emissions exhibit an exponential increase with rising amounts of hydrogen if the engine control system does not intervene by leaning the air/fuel mixture (Mehra et al., 2017; Yan et al., 2018; Fichtner et al., 2023).

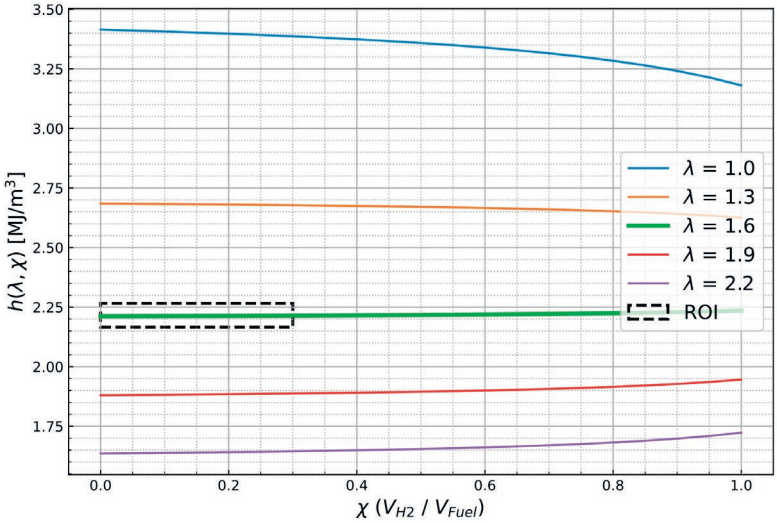

Figure 2. Lower Heating Value *h* of air/fuel mixtures with various equivalence ratios λ versus hydrogen fraction χ. The region of interest (ROI) for the experiment is indicated by the dashed black box.

3.2 NOx-Emissions – Correlation with Boost Pressure and Power

To address this issue, a comprehensive parameter scan was conducted. The parameter space included power outputs *P* ranging from 60kW to 110kW in steps of 10kW, hydrogen concentrations of 0 - 30% vol., and equivalence ratios of λ = 1.55 - 1.95. Figure 3 shows the most interesting correlation found in the experiment. The nitrogen oxide emissions measured at the stable operating points are plotted against the boost pressure. Each data point corresponds to a distinct engine adjustment in terms of power output, equivalence ratio, and hydrogen content of the fuel supplied. Each engine parameter was measured continuously at an interval of one second. The data points shown in Figure 3 represent the average of 100 consecutive measurements taken over a period of 100 seconds, the error bars represent the standard deviation.

Apparently, the data is on asymptotically falling curves. As a first approach to describe the correlation between boost pressure and nitrogen oxide emissions mathematically, a power law model was used.

3.3 Mathematical Model

Plotting the NO_x emissions against the boost pressure revealed that the emissions follow asymptotically falling curves, with each curve corresponding to a specific power output *P*. When plotted on a double-logarithmic scale, a family of parallel lines emerged,

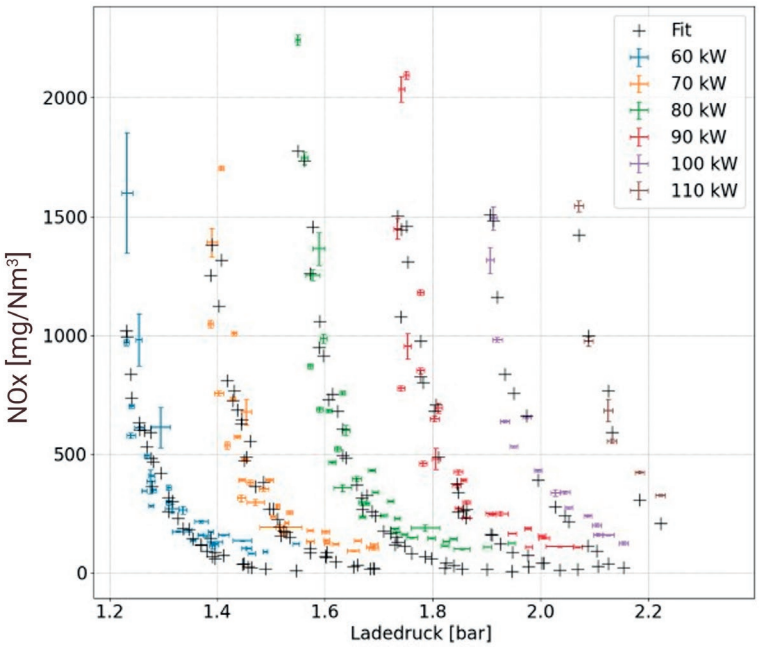

Figure 3. Nitrogen oxide emissions versus boost pressure. The measured data forms exponentially falling curves. Each curve represents a certain power output.

suggesting that the relationship between NO_x emissions and boost pressure could be approximated using the following equation:

$$\log(NO_x(p)) = \log(a) + b \cdot \log(p) \tag{1}$$

Thus, $\log(NO_x(p))$ can be represented by a straight line with intercept $\log(a)$ and slope b, where both parameters depended on the power output P. For simplicity of the model, a linear dependency was assumed for both parameters, resulting in the following equations:

$$b = \alpha + \beta \cdot P \text{ and } \log(a) = \gamma + \delta \cdot P$$

The final model for NO_x emissions, $NO_x(p,P)$, is thus given by the following expression:

$$NO_x(p,P) = e^{\gamma + \delta \cdot P} \cdot p^{\alpha + \beta \cdot P} \tag{2}$$

It is important to keep in mind, that the given model is a first approach. The exponential relationship and the power relationship are not based on physics but justified by straight lines in a log-log plot of the data. The linear dependency of the parameters (b and $\log(a)$) and the engines power output are just a first try.

The mathematical model was fitted to the data and was found to describe the curve progressions well (see Figure 3). It must be mentioned that the constants are probably individual for each engine. The optimal fit for the engine in the experiment presented here was obtained using the following constants:

$$NOx\ (p,P) = e^{-(4.03-0.23 \cdot P)} \cdot p^{-(8.56+0.10 \cdot P)} \quad (3)$$

The comparison between measured data and fit shows that there is still potential for optimization in the model. For a first approach, however, the result is quite promising. The circumstance that nitrogen-oxide emissions decrease as boost pressure increases is reproduced well. This outcome was expected since a high boost pressure at a fixed power output implies a lean mixture. A leaner mixture results in a colder combustion process, which in turn leads to lower nitrogen-oxide emissions (Ma, 2008).

3.4 Real-Time Capability

After the determination of the model constants, a continuous engine run lasting 140 minutes was conducted to test the model. During the engine run, the hydrogen content in the fuel was varied between 0 and 30 percent by volume. Power output, equivalence ratio, and ignition timing were also varied. Each of the mentioned parameters has a significant impact on NO_x emissions (Fichtner et al. 2023; Ma et al. 2010; Quader 1974).

The results are presented in Figure 4, which shows that the model provides a good approximation of the actual measured emissions. In general, our model is suitable for

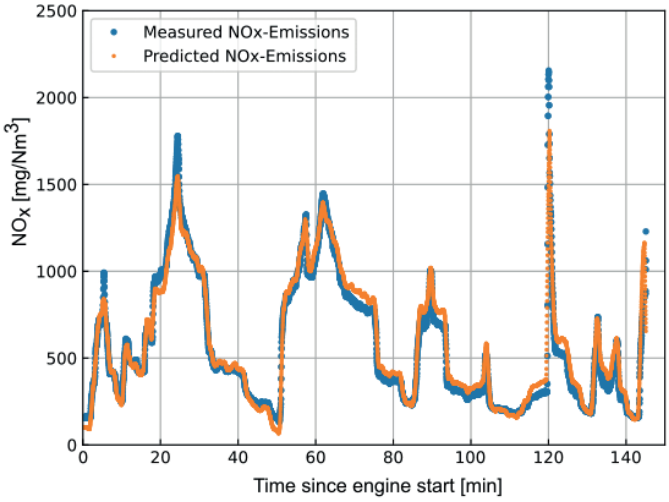

Figure 4. Nitrogen-oxide emissions during a continuous engine run of 140 minutes. Blue dots represent the measured data, orange dots are calculated from boost pressure and power output with the help of the presented mathematical model.

application as virtual NO_x sensor which can detect emissions independently of the fuel gas supplied. Before that, the model needs to be further improved, but the first approach presented here is promising. This also means that the chosen approach is suitable for the development of a mixture control system for cogeneration power plants that can effectively respond to hydrogen-containing fuel gases.

4. CONCLUSION

In summary, our study investigated the impact of hydrogen-containing fuel gases on nitrogen oxide emissions in cogeneration power plants. We found that gas engine controls which keep the lower heating value of the air/fuel mixture constant, are unable to respond to hydrogen admixture within the allowed range in Europe and above. This results in exponentially increasing nitrogen oxide emissions with increasing hydrogen content. To address this issue, we conducted a comprehensive parameter scan and developed a mathematical model that describes the impact of hydrogen content and other engine parameters on nitrogen oxide emissions. The model was validated in a continuous engine run, demonstrating that it can effectively detect emissions independent of the supplied fuel gas. Our findings highlight the potential of our approach to develop a mixture control system that can respond appropriately to hydrogen-containing fuel gases in cogeneration power plants, thereby mitigating their impact on nitrogen oxide emissions.

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AUTHOR CONTRIBUTIONS

Johannes Fichtner: *Conceptuation, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Software, Supervision, Visualization, Writing – original draft.* Adrian Gegner and Jan Ninow: *Validation.* Joerg Kapischke: *Funding acquisition.*

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RECYCLING OF LABORATORY PLASTIC WASTE – A FEASIBILITY STUDY ON CELL CULTURE FLASKS

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ABSTRACT: Laboratories contribute considerably to the global production of plastic waste. It was estimated that labs involved in biological, medical, and agricultural research produce around 5.5 million tonnes of plastic waste per year (Urbina et al. (2015) Nature 528, 479). Due to chemical and biological contamination, lab plastics pose a challenge for recycling and are most often used as single-use items. After use, these items are waste, and a recycling process or management system is missing. In cell culture, polystyrene (PS) vessels are predominantly used because of their favourable properties, such as transparency, stability, good cell-adhesive properties, and biocompatibility. This paper aims to present the recycling potential of the "laboratory plastic waste" using PS cell culture flasks, after decontamination by autoclaving, as an example. The different steps of the recycling process of the plastic material are presented as well as the biological evaluation of the recycled material. The mechanical and rheological characterization of the recycled PS parts shows a minimal reduction of material quality. The biological evaluation indicates that the recycled material does not meet the requirements of cell culture vessels. Further research is necessary to improve the transparency and surface-cell-adhesion properties of the parts made of the recycled material. Nevertheless, due to the good mechanical properties of the PS recycled material, it can be reused in other applications.

KEY WORDS: *Plastic waste; laboratory plastic waste; cell culture flasks; recycling.*

1. INTRODUCTION

Plastic articles are used throughout the world because of their beneficial features, such as durability, flexibility, and cost-effectiveness (Bennett and Alexandridis, 2021). This is why global plastic waste has increased tremendously within the last decades. Currently, 400 million tonnes of plastic waste are being produced every year (United Nations Environment Programme).

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Research laboratories make use of single-use plastics in many routine applications and thus strongly contribute to the growing amount of plastic waste. It is estimated that labs involved in biological, medical, and agricultural research produce around 5.5 million tonnes of plastic waste per year (Urbina et al., 2015). In recent years, individual scientific working groups have made attempts to reduce and recycle plastic waste (Alves et al., 2020; Howes, 2019; Reu et al., 2019). However, recycling contractors are often concerned about recycling of lab waste due to biological or chemical contamination (Howes, 2019).

In cell culture laboratories, particularly polystyrene (PS) cell culture vessels are used for cultivation of mammalian cells because of their favourable characteristics, such as transparency, stability, good cell-adhesive properties and biocompatibility. Moreover, manufacturing of PS vessels is relatively simple and cost-effective. To facilitate cell adhesion, PS surfaces can be easily modified by plasma treatment or coated with polymers or proteins (Lerman, et al., 2018). After usage, PS cell culture flasks are decontaminated by autoclaving and then disposed of as residual waste (Figure 1). In the past, cell cultivations were carried out in reusable glass bottles. However, due to the effort involved in cleaning and sterilizing glass labware, a return to this approach is not conceivable. Cell culture is a key technology in life sciences and indispensable in many areas of biotechnology and medicine, where it enables the production of biopharmaceuticals, tissue engineering or the cytotoxic assessment of chemicals without animal experiments. It is therefore assumed that PS plastic waste will even increase in the coming years.

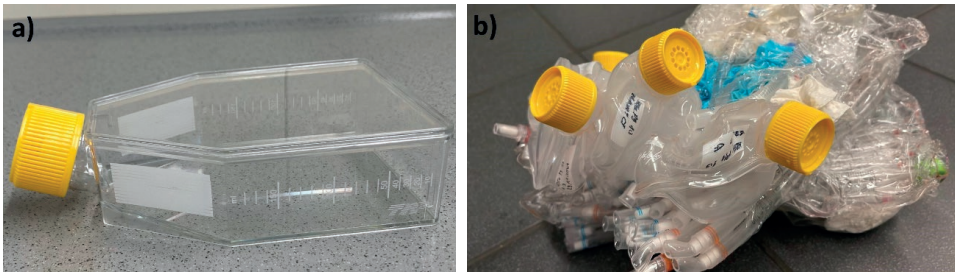

Figure 1. PS cell culture flask (a) and mixed, autoclaved lab waste with cell culture flasks (b).

The aim of this study was to set up a recycling process for autoclaved PS cell culture flasks in order to re-use the recycled material for the production of new cell culture vessels. Here, the different steps of the recycling process of the plastic material as well as results of material analysis are presented. To determine the characteristics of the recycled material for cell culture purposes, we performed cell culture experiments and subsequent microscopy with the standard cell lines CHO-K1 and 3T3-L1.

2. MATERIALS AND METHODS

Collection of cell culture flasks

For cell cultivation, T75 polystyrene cell culture flasks (TPP®) with a surface area of 75 cm^2 were used. After cultivation, empty flasks and caps were collected separately and autoclaved for 20 min at 121°C and 250 kPa (Varioklav 400 E, H+P Labortechnik).

Recycling process

Recycling was performed in three steps: separation (manual separation), shredding (moditec G1S ACP), injection moulding (Demag Ergotech 35-115).

Material analysis of PS

Polymer materials were identified by infrared spectroscopy (FTIR, Thermo Scientific Nicolet iS50). Samples of shredded PS for cell culture experiments and tensile testing specimens (1 BA ISO 527-2:2012) were prepared by injection moulding using a Demag Ergotech 35-115 with a clamping force of 35 tons. Characterization of mechanical behaviour of shredded PS was done using a tensile testing machine (Instron 4411 with 5 kN load cell) according to ISO 527:2012 with samples type 1 BA, where 5 samples were tested. Melt Flow Index (MFI) of PS samples was determined with Meltflixer ^{LT}. Microscopic evaluation was done with an inverted microscope (Avantor IT415PH). Images were taken using a camera (Bresser MikroCam PRO HDMI).

Cell culture

CHO-K1 cells (ATCC) were cultured in DMEM-F12 medium supplemented with 10 % (v/v) fetal bovine serum, 1 % (v/v) Penicillin/Streptomycin and 2 mM Ala-Gln. 3T3-L1 cells (ATCC) were cultured in DMEM (high glucose) supplemented with 10 % (v/v) neonatal calf serum, 1 % (v/v) Penicillin/Streptomycin and 20 mM Hepes. Cultivation was performed in a CO_2 incubator (Heracell 150, Thermo, 37 °C, 5 % CO_2). All components of the cell culture media were purchased from Sigma Aldrich.

Biological evaluation of PS materials

Plates (approximately 1 mm thick) of new and recycled PS were broken into smaller pieces of approximately 5 mm to 1 cm in diameter. For disinfection, the fragments were quickly rinsed in 70 % Ethanol and placed into Petri dishes in a laminar flow hood (Labgard ES Class II Biological Safety Cabinet). After ethanol was completely evaporated, PS pieces were transferred into 6-well plates (Greiner Bio-one). 4 ml of cells in culture medium ($5 \cdot 10^4$ cells/ml) were seeded on the different PS materials in 6-well plates and cultured for up to six days. For microscopic evaluation using an inverted microscope (Avantor IT415PH), samples were transferred into a new 6-well plate. Microscopy was performed at 100× or 200× magnification. Images were taken using a camera (Bresser MikroCam PRO HDMI).

3. RESULTS

Before setting up a recycling process, the plastic materials of unused T75 cell culture flasks (TPP®) were analysed visually (Figure 2) and by infrared spectroscopy (Table 1). The flasks consist of PS, whereas the yellow cap is made of high-density polyethylene (HD-PE). Moreover, the latter contains a polytetrafluoroethylene (PTFE) sealing/filter, a synthetic fluoropolymer that is used in numerous applications. To ensure proper recycling of the thermoplastic polymers, the separation of the different polymer fractions is necessary, as the combination of different types of plastics is a substantial obstacle to recycling (Sover et al., 2019, 2021 and 2022). Different companies work in this field of materials separation and provide good technical industrial solutions. In this study, the flasks and caps were separated manually to have a better understanding of the behaviour of each material after recycling and to avoid contamination with other materials. Here, separation was done for new cell culture flasks (Figure 2 a) and flasks collected after having been used with cultured cells and autoclaved (Figure 1 b).

Table 1. FTIR identification of the materials from PS cell culture flasks.

component of cell culture flask	FTIR analysis		
	material	probability [%]	weight [g]
flask	PS 454 H	98.57	43.49
cap	HD-PE BorPur MB 7541	92.17	3.98
filter for ventilation	PTFE	71.81	
printing	Butyl benzyl phtalate	70.13	

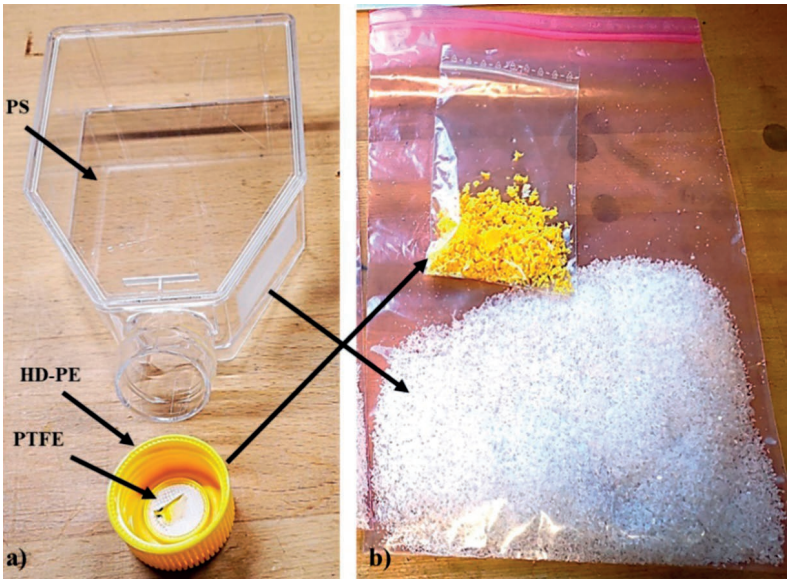

Figure 2. Cell culture flask, components and materials (a) and granulated components (b).

Recycling was performed in three steps: separation, shredding and injection moulding. As cell culture materials are usually autoclaved at high temperatures (121 °C) and high pressure (approximately 250 kPa) for biological decontamination, we aimed to find out about the impact of this harsh treatment on the plastic materials. For this purpose, the recycling process was compared for new (unused) and used (autoclaved) cell culture flasks. After shredding, samples were prepared by injection moulding in order to assess polymer quality regarding degradation. This evaluation was carried out after the mentioned processing steps which are state of the art in different recycling companies.

The processing of the PS flask did not cause any problems following the recommendation of parameters for PS polymer. 60 mm x 60 mm plaque samples were produced to inspect the transparency properties of the polymer material after the recycling process and for later biological evaluation. Moreover, tensile testing specimens (1 BA ISO 527-2:2012) were prepared by injection moulding (Figure 3).

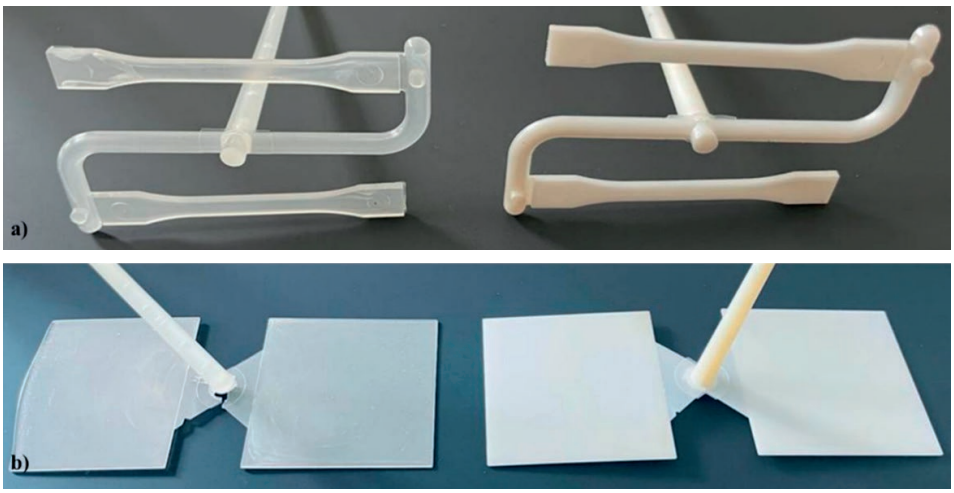

Figure 3. Tensile testing samples (a) and 60 × 60 mm plaques (b) of PS materials from the new (left) and used (right) flask prepared by injection moulding.

After processing, the properties of recycled material were analysed and compared to new material. Validation of Melt Flow Index (MFI) indicated no major differences between the two types of materials as MFI of the polymer from the used and shredded flasks was 2.9 g/10 min (ISO 1133, 2.3 kg, 190°C, measured with Meltflixer ^{LT}) while the MFI of the original flasks was 3 g/10 min.

Characterization of the mechanical behaviour of the shredded new flasks and used flasks was performed using a tensile testing machine according to ISO 527:2012 with samples type 1 BA, where 5 samples were tested. The results are presented in Table 2.

Table 2. Results of tensile testing of shredded PS polymer.

parameters	tensile testing results (ISO 527)	
	new flasks	used flasks
max. Force (Fmax) [N]	560	530
E-Modulus [MPa]	1337	1352
tensile strength (Rm) [MPa]	48.29	46.63

Also here, observed differences in the mechanical properties of the shredded PS polymer for new flasks and used flasks were minimal (under 5 %), which implies that the polymer material does not lose its mechanical characteristics after autoclaving.

Visual comparison of recycled PS material with new, not recycled material revealed that transparency is evidently lower after recycling (Figure 4). This obvious effect can be a problem for re-utilisation of the PS recycled polymer in the production of cell culture flasks, considering that, in cell culture, cell morphology and proliferation is usually inspected by transmitted light microscopy. Moreover, during microscopic evaluation of the recycled material, it was not possible to adjust the sharpness on the microscope, probably due to surface characteristics (Figure 4 d).

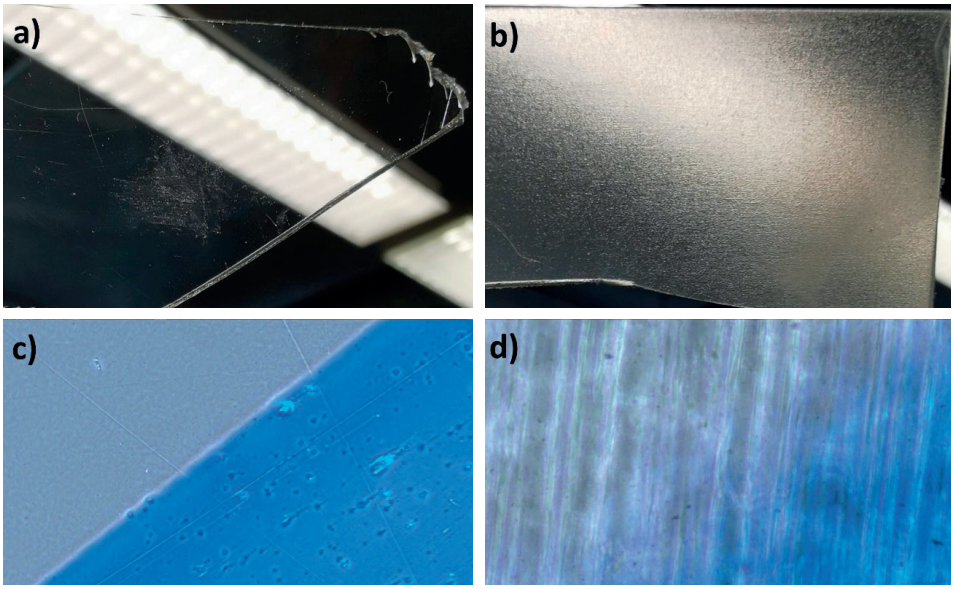

Figure 4. Visual comparison of transparency of new cell culture flask (a) and recycled material (b) and microscopic inspection of the surfaces (c: new PS; d: recycled PS). To adjust sharpness on the microscope, a blue line was drawn on the materials.

In their natural environment, the majority of mammalian cells attach to an extracellular matrix. In the artificial setting of cell culture, they adhere to the surface of a cell culture vessel instead. In order to determine the biocompatibility of the recycled PS, two different cell lines were seeded on small plates of new and recycled PS and microscoped after six days of culture (Figure 5). On the original PS material, CHO-K1 cells adhered and grew to confluence, showing an epithelial-like morphology. Adherence was also observed for 3T3-L1 cells exhibiting typical spindle-shape morphology. In contrast, on recycled PS, microscopy was complicated because of the cloudy material surface. However, discrete shapes of cells were detectable, although at decreased number. It is therefore assumed that cell-adhesive properties of recycled PS are reduced.

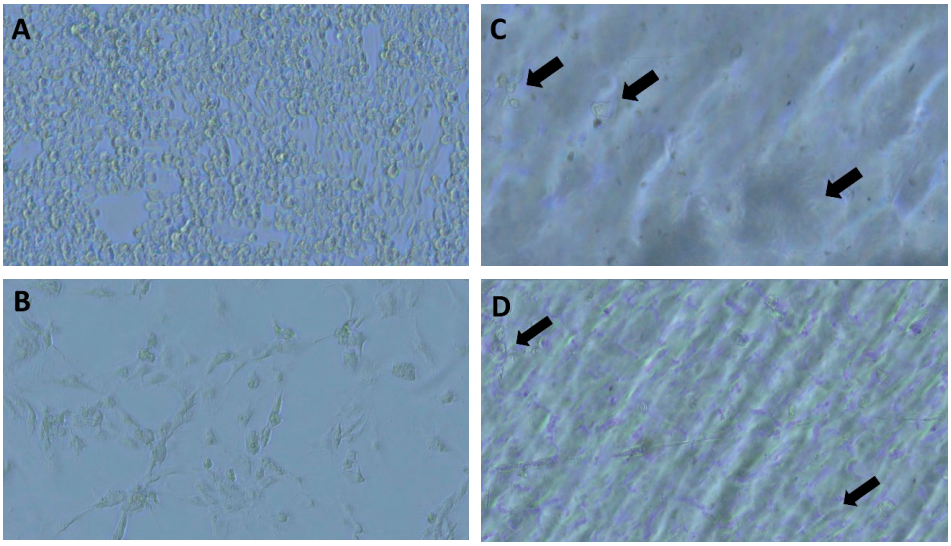

Figure 5. Biological evaluation of new cell culture flask and recycled material. CHO-K1 (a, c) and 3T3-L1 (b, d) cells were grown for six days on different materials in 6-well plates. On new cell culture flasks (a, b), cells adhered and showed typical shape. On recycled material (c, d), cells are not clearly visible. CHO-K1: 200× magnification; 3T3-L1: 100× magnification. Discrete shapes of cells are exemplarily indicated by arrows.

4. CONCLUSION

Our investigation shows that the recycling of cell culture flasks is possible with a minimal decline of mechanical and rheological properties of the recycled PS. The decrease in transparency is substantial and affects the potential re-use of this material for cell culture purposes. However, with the aid of additives and changes of process conditions, transparency could be enhanced (Guzman-Puyol, et all., 2022). So far, the important feature of good cell adhesion was not fully achieved by the recycled polymer. This property could be improved by surface modifications, e.g., plasma treatment (Lerman, et al., 2018).

However, the recycled PS polymer promises to be readily usable for other (non-cell culture) applications, e.g. white goods and automotive, where the mechanical properties are more important than biocompatibility and microscopic properties of the material. For those non-cell culture applications, it is essential to ensure the safety of the PS polymer. This is even more important as some cell culture labs work with hazardous biological organisms or genetically modified cell lines. During autoclaving, those organisms are killed. However, it was shown that DNA can resist denaturation at high temperatures (Wang et al, 2014). Thus, our future efforts aim to confirm that the recycled material is free of DNA from previously cultured cells to make it usable for non-cell culture purposes.

Overall, the price-benefit of the recycled PS polymer can be interesting for recycling companies. This might represent a good step towards a cycle economy helping to re-use plastic material and act environmentally responsible.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

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PLATFORM ENGINEERING FOR CLOUD-NATIVE ORGANIZATIONS

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ABSTRACT: Cloud Computing allows companies to scale seamlessly, providing a broad range of state-of-the-art services. Another promise is to free users from the operational and administrative burdens. However, with the advent of cloud-native applications, this promise becomes questionable – especially when DevOps principles are used during development. Experience in practice shows that teams often struggle dealing with both the infrastructure, finding the right architecture, and implementing business logic. When working in decentralized teams, things are even worse, as standardization across teams cannot be assumed. To tackle those issues, automation by means of techniques such as Infrastructure-as-code help to ease to cope with infrastructural concerns. However, when working with several teams in a decentralized manner, operational overhead is still there. Organizations struggle with standardization of infrastructure code and there is no clear centralized visibility for security-related concerns within the development lifecycle. To address these issues, we propose two things: First, building up a Platform Team, which serves as an organizational structure for continuous delivery. A Platform Teams can be the size of a typical small DevOps Team and support the whole organization with standardized security-hardened modules. Second, an Ops-Platform is needed that is operated by the Platform Team to centrally provide and maintain those modules. Other Dev-Teams can then consume those modules. In this paper, we report insights from the implementation of this approach in practice. We find out that developers are 75% less focused on operations by using such a platform and name specific success factors.

KEY WORDS: *Cloud Native Applications; DevOps; Infrastructure-as-Code; Platform Engineering; Platform Team.*

1. MOTIVATION AND INTRODUCTION

Within the last years, enterprises have already migrated large portions of their workload to the cloud – whether it is a private, public or hybrid cloud. However, many companies still fail to grasp all the benefits of cloud computing. According to the State of DevOps report

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released by Puppet and DORA (DevOps Research & Assessment) (Puppet Labs, 2023), that highlights a DevOps maturity model, the overwhelming majority of companies are struggling with to reach the highest level of DevOps majority. This results in a set of problems to be solved: First, long lead times can be observed. Secondly, processes are often carried out manually, usually initiated by means of tickets created by developers. Third, the all overall complexity of the tools and the way how to integrate them is usually high leading to the fact that developers are overwhelmed. Last, waiting times slow done developers as many companies lack an internal self-service developer platform.

To tackle those issues, highly mature DevOps organizations tend to have their organization having structured in both application teams that are stream-aligned and platform teams (López-Fernández et al., 2021). Basically, stream-aligned teams are development teams that are building code and putting them into production. On the other hand, platform teams support that teams and might provide among other things (Leite et al., 2020):

- Platform servicing such as CI/CD and infrastructure provisioning by using industry-wide best practices such as Infrastructure-as-Code (IaC).
- Evangelization and mentoring DevOps practices for promoting cultural values, such as communication, transparency and knowledge sharing.
- Rotary human resources, which means that platform teams might help and provide product teams with human resources when these teams lack of specific skills to accomplish their work.

In this paper, the research question is how such a platform team can be formed to support enterprises with cloud-native technologies in an efficient manner. We will show how a platform team integrates with product teams within an organization and depict their responsibilities. In particular, we focus on the technical requirements for efficient infrastructure requirements based on Infrastructure-as-Code and GitOps.

The paper is structured as follows: First, we show related work. Second, we give an overview about the technical background. In the following, we will depict the requirements and the processes for an efficient platform team. Last, we will discuss considerations for future work.

2. RELATED WORK

Platform Teams and Platform Engineering is a relative new trend. First publications on platform teams date back to 2020. In their paper, Leite et al. (2020) describe platform teams as an organizational structure for continuous delivery and provide information about their role in an organization and how they interact with product teams.

Srivastava (2023) argues that Platform and Site Reliability Engineering is just as crucial for startups as it is for bigger organization. Done right, it enables companies to efficiently deliver high-quality, secure, compliant, robust, and reliable products to their customers.

Seremet & Rakic (2022) describe how Platform Engineering and Site Reliability Engineering go hand in hand to unlock the productivity of application development teams. In detail they describe how both roles share a common set of principles and how they differ from each other.

In their State of DevOps Report: Platform Engineering Edition Puppet (2023) describes what makes platform engineering the key to DevOps success at scale, why platform engineering is on the rise and how platform engineering benefits the entire organizations when it is done well.

3. BACKGROUND

Platform Teams for cloud-native environments don't come from nowhere – instead they use state of the art software engineering principles to accelerate software delivery. For infrastructure provisioning Infrastructure-as-Code (IaC) (Morris, 2020). has become a de-facto standard. Basically, the idea behind IaC is to declaratively the describe the target-state of the cloud environment within a source control system. IaC tools then apply all necessary changes to rollout cloud resources in the target environment. IaC principles help to create consistency, speed up deployment, improve accountability, and increase efficiency while also being able to help mitigate unnecessary costs.

GitOps (Beetz & Harrer, 2021) extends the idea of IaC for all kind of deployments – not only infrastructure provisioning. Git remains the single source of truth and deployment information is described in a declarative way as well. In addition, an application deployment tool is to be used and there is a monitoring tool in place, which continuously reconciles the states and carries out changes in the target system if necessary.

Site Reliability Engineering – also called SRE – describes a set of best practices for automating IT infrastructure tasks such as system management and application monitoring. The focus of SRE is on improving the reliability of scalable software systems amidst frequent updates from the development teams. A key component of SRE is observability: By defining Service Level Objectives (SLOs) and measuring actual Service Level Indicators (SLI), teams get a better understanding of reliability and have ways to define system availability goals. In addition, SRE puts its focus on a cultural change in such a way that every failure is seen as a failure in the reliability system.

4. PLATFORM TEAM ENGINEERING FOR CLOUD-NATIVE-ENVIRONMENT

In many organizations, DevOps teams are solely responsible for all the aspects within a software product. However, when dealing in cloud-environment and possible with Kubernetes, many application teams struggle with efficient processes for infrastructure provisioning and security issues. Platform teams help to address those issues by abstracting infrastructural issues from application teams.

Platform team and application teams can be part of an organization. However, companies might not have the size or the required skills to build up a platform team. In that case, platform engineering can be offered as a service across organizations.

For such offerings, standardization is a key requirement as it increases efficiency for supporting application teams. In addition, tooling is needed that provides support for consuming provided IaC modules as well as having self-service capabilities. For GitOps support and facilitating security best practices, we propose to set up a well-defined structure in a Git repository that enables to go infrastructure and application deployments hand in hand.

Figure 1 depicts the responsibilities and interaction of the Platform Engineering team. As described, the Platform Teams provides an abstraction layer above the underlying infrastructure – usually a public cloud hyperscaler or a private cloud. It then provides the following services to the product teams:

- Most important, a DevOps tool with pipeline support in order to run workflows is provided to run workflows.
- The Platform Team provides standardized modules that are optimized in terms of programming and security best practices and are compliant for the organization.
- Application Teams need a way to interact with the Platform Team. In most use cases, using Git is sufficient in order to support IaC pipelines and GitOps workflows. For advanced use cases, a self-service catalog or an internal developer platform can be used.
- Besides infrastructure deployment support, a CI/CD platform should also be provided. Functionality should include at least support for container images builds and app delivery.
- In order to support SRE, observability should be integrated in the platform tooling and all provisioned resources should have observability support included.
- Platform tooling should support product teams in the complete DevOps lifecycle – from building, testing to operating.
- If Application Teams need support, the Platform Team might provide consultancy and human resources to the respective teams.

Figure 1 depicts the relationship between the Platform Tooling and the Applications that are built on top of it.

The platform engineering team serves as a central point of contact for various aspects of the infrastructure and platform. As the team is responsible for the development, deployment and management of the cloud platform, it can act as the main point of contact for other teams within the organization.

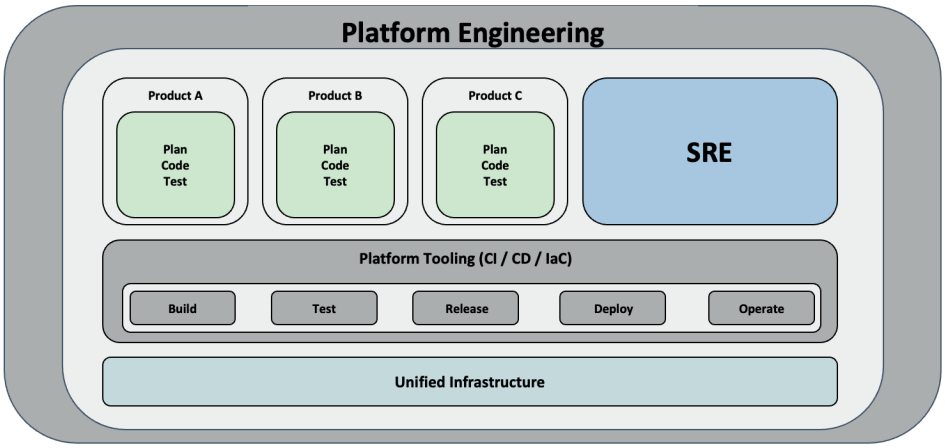

Figure 1. Overview of Platform Engineering.

5. CONCLUSION AND FUTURE WORK

In this paper, we have conceptually shown how Platform Engineering can be achieved and what kind of interactions between the Platform Team and Product Team exist. We described the service offerings and the tooling provided by the Platform Team. In the future, we want to publish dedicated business cases on how Platform Engineering works in practice. We are working on a maturity model for Platform Engineering as well as describe the technical capabilities that are needed in the Platform Tooling.

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RESEARCH ON RELEVANT VARIABLES RELATED TO ENTERPRISE CO-CREATION AND INNOVATION FOR BETTER PRODUCT OUTPUT

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ABSTRACT: Co-creation is a business strategy to excel in product and service creation and improvement through collaborative innovation involving stakeholders, especially customers. The aim is to produce outcomes that are more valuable to the target market, through customer aligned and enriched needs and knowledge, skills, and creativity base. Present AI times show an accelerated evolution in most business key areas. Proactivity to change is paramount for any organization to survive. What measurable organization traits better relate to co-creation and innovation? Can these relationships allow to identify businesses better posed for success and allow to prioritize certain activities for a better performance? Study deepens on different enterprise variables related to innovation and co-creation, as causes or effects. Software and technological business as well as those present in short cycle physical product markets relate to co-creation. Business in service-related activities also show this relationship. Multisector entities may perform better than unique sector of activity ones. Public activities are less result driven and less prone to co-creation and clear improvement opportunities. Budgets seem to affect co-creation, therefore so should do economic cycles. For future research: faster time to market, cost-savings, internal process improvement, customer loyalty and engagement, eco-sustainability concerns and preferences of stakeholders, incorporated into products and services. Internal knowledge and innovation management culture and processes are key to innovation success and relate directly to operational performances.

KEY WORDS: *Innovation; co-creation; product creation; value chain improvement; customer needs; variables.*

1. INTRODUCTION

Currently the framework in which companies operate changes rapidly due to various driving factors: the environmental situation, Artificial General Intelligence (AGI) and the

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data it is fed with for training, and the globalized strong fluctuation of markets including that of energy and materials as well and related to present geopolitical turmoil. These accelerated changes, after years of free, stable trade conditions, exacerbate competition and the need for rapid evolution of all entities. This evolution of companies must logically be adaptation: in accordance with changes needed. This is where innovation is more than ever paradigm for improved organizational changes as well as related product and service improvement. As always, the guiding backbone for innovation must be the stakeholders value chain growth. Meeting customer's needs is the fundamental aim in the stakeholders value chain. And they can't be better met than with co-creation and customer centered collaborative innovation processes.

2. METHODOLOGY

Hypothesis and objectives

Any tools to predict any enterprise expected innovation performance is a great asset. The aim of the study is the identification of input and output characteristics that relate to innovation and co-creation as a fundamental first step. Studying the nature of relationships between these output and input variables is another step in the way to a predictive model.

Stages and methodology

First trough innovation concepts and second, enriched and corroborated through a basic review of scientific literature, entities characteristics or variables that are related to innovation and co-creation are proposed.

3. RESULTS

Characteristics of enterprises that could be related to innovation and co-creation from innovation and present common knowledge

Enterprises articulate innovation systems based on concepts between which three could be considered main pillars: knowledge, technology, and interactions, being the first two, the basic components of innovation. Internal knowledge level affects the performance both of inventions and development. Knowledge management is increasingly important, also considering powerful stablished AI algorithms and new AGI algorithm analysis technology using big data for training.

Funding is not indispensable, but innovation requires risk taking because resources are used sometimes without a guaranteed output. Therefore, firms without capital resources have greater difficulties innovating. Since innovation is a complex activity, requiring resources and management, enterprise size plays also a role, except for emerging markets or technologies, where small, pioneers and first to arrive enterprises have a naturally

innovative uprise. Similarly, budget size or relative size to income in certain areas like design and research and development show effort and compromise by companies. Sustained effort should yield innovation and co-creation results. Economic cycles affect budgets so they should also affect innovation and co-creation.

Even though globalization and online working technologies have decreased its influence, localization of the enterprise still plays a significant role. External knowledge and innovation dynamics are heavily influenced by local government policies, public institutions, educational institutions, existing technological infrastructures and legal frame. All these may boost or ballast innovation efforts. Universities and other educational entities feed the entities workforce initial knowledge. Also, innovation organizations tend to cluster. When this happens, innovation and cooperation benefit from the clustering dynamics such as high knowledge companies and high skilled personnel density and availability. Strong economic and industrial areas where corporations strongly drive suppliers into co-creation, not only at a component level, are frequently sectorial hotbeds of innovation. Automotive industry is a classic example of this. Economic, activity and social diversity favor innovation, since besides similar interests, also different interests concur in a same spot. knowledge mixing and crosspollination of ideas, learning and applying positives from other activities is more likely to occur in these areas than in homogeneous environments. The result is a richer innovation seedbed and later easier translation of different ideas into new products and services. These conditions happen in or close to urban areas.

Also due to diversity in knowledge, multisector entities may perform better than unique sector of activity ones.

Rapid changing markets or those where product changes rapidly due to fast technology advancement are populated by innovation centered companies. Otherwise, they would have disappeared by market nature. Software and technological business as well as short cycle product markets are an example.

Product nature will affect innovation outcome. Service-related business show a closer relationship to co-creation activity. Service is by nature easily tailored to customer needs more than physical products, which have a wider pool of design constraints. Product wise, strategies based on mass scale production or cost reduction may yield different innovation outputs than strategies based on custom, new or high-quality premium products.

Public activities are less improvement proactive since their existence is less or not tied to performance. There may not be other entity for customers to choose, no competence can take over its activity. Consequently, they are less prone to co-creation and innovation, but in the other hand can show clear and easy improvement opportunities through them.

As outputs that could measure co-creation and innovation return, are gains in market share as well as in new markets. New products successfully launched into market could also be gross indicators to which they would most probably contribute. Ideally, they should be pinpointed to projects. Internal efficiency gains and sustainability indicators in

areas where innovation related projects had taken place, as well as shortened process and development cycles are also possible indicators. Some of this information is internal to companies and hard to obtain for academic purposes.

Characteristics of enterprises that could be related to innovation and co-creation from basic review of scientific literature

A simple systematic approach is adopted, identifying 9 relevant articles, 7 sought in Web of Science database and 2 additional ones that were judged to be relevant. We limited the search strings to the following in Web of Science database: TI=(((innova* AND (factor* OR variable*)) OR ((co-creat* OR cocreat*) AND (factor* OR variable*)))) AND TS=(innova* OR co-creat* OR cocreat* OR sustainab*), with the use of asterisks at the end of words enabling the search for different endings. Additionally, no restrictions to date or country of publications were placed.

Market, law and regulation knowledge, inter functional collaboration, innovation-oriented learning and R&D investments are the four main success factors for environmentally sustainable product innovation (Cortimiglia et al., 2014).

A study of product innovation, the influence of organizational process factors and capabilities on development performance (Tatikonda et al., 2001) show that development organizational process factors studied are associated with achievement of operational outcome targets for product quality, unit cost, and time-to-market. This achievement of mentioned operational outcomes aids the achievement of market outcomes, so development capabilities are a valuable resource. Also, these relationships are robust under conditions of technological, market, and environmental uncertainty, where innovation is more than ever needed.

Another article (Cooper, 1999) states that factors for success fall into two categories. The first is the right selection of new product projects. This indicates the importance of market knowledge, thus marketing department. The second category contains factors referring to doing right the projects. This includes complete and early product initial definition, strong customer voice following, well resourced and planned projects, capable cross-functional teams with strong leaders and global and multimarket research. Interestingly, the lack of efforts in these factors operate as "blockers" of the innovation and development process.

A meta-analytical investigation over new product success (Evanschitzky et al., 2012) indicates that local cultures affect with success factors weakened for individualistic countries and strengthened in risk-averse countries. Also, that working in varied cultural contexts will result in different backgrounds of successful new product companies.

Internal factors are analyzed in an article (Galende et al., 2003) and the following relevant are mentioned: size, debt, human resources, organizational and commercial resources, diversification, and internationalization.

A study with a sample of over 6000 manufacturing firms from the Spanish Survey of Technological Innovation 2000 (Vega-Jurado et al., 2008) states that internal research and development technological competences have a principal role in product innovation and that with such strong competences, non-industry agents derived from technological opportunities affect less to innovation.

Although another study (Donate et al., 2011) has a scope limited to high-rate innovation industries, the analysis of organizational factors influencing knowledge practices and innovation, show that the following factors: human resources, leadership and culture, when are knowledge-centered will elevate the exploitation of innovation capacity of the firm.

A study over data from Spanish automotive firms (Segarra-Ona, 2011) showed that those that innovate rely greater in information. Also, that companies which consider market information sources -such as customers, suppliers, competitors, and other external sources- as important in the process of innovation and development of new products and markets are also more environmentally oriented.

A study with the PITEC Innovation in Companies Survey (Segarra-Ona, 2011), Spanish companies show that company and market size, formal innovative activity (reflected by registered numbers of patents) as well as total expenditure on technology acquisition influence the eco-innovative orientation of firms.

4. CONCLUSIONS

From results we propose the search for variables related to the following concepts in a valid data set. They are classified as internal and external inputs and outputs for a later study of their relationship with innovation and/or co-creation.

Internal inputs

Knowledge excellence culture and management effort variables: registered patents, internal formation budgets, educational level of staff, R&D and Innovation budgets and personnel (staff quantity internal and external), also related to innovation internal processes management, software and hardware licensing budgets or acquisitions.

Innovation internal processes management: assigned budget, staff and number of innovation and development projects for products or internal processes (also related to internal interaction). Diversification: other departments staff dedication to R&D and innovation projects (personnel, hours, budget...). Average R&D and Innovation staff age.

Technology effort: software and hardware licensing budgets or acquisitions, machinery renovation budgets or expenditure, IT budgets or expenditure, process engineering budget and personnel, quality improvement budget and personnel.

Stakeholders and customer interaction (co-creation): local entities and customer involvement in projects (number of projects and staff involved).

Collaboration with other entities: joint ventures with other companies (number or dedicated budget and staff involved), collaborative projects with local educational and technological entities (number or dedicated budget and staff involved).

Marketing function: Marketing budget, especially for market study (not selling strategies). Personnel assigned to market analysis.

Funding and size: public or private funding, income, personnel number, company growth (income and quantity).

External inputs

Localization: distance to urban area, urban area size, urban area number of superior and vocational educational institutions, public local educational expenditure, local median gross income, average gross income of first local 100 firms, average gross income of first local 100 firms in same business activity, average gross income of first local 100 firms in IT, number of foreign working permits working locally, immigration data, English language local knowledge data.

Outputs

Quality data (scrap losses, customer satisfaction indexes...), time to market data, diversity of markets product and geographically wise, new product growth data (number of products, income...), new market share gain data (number of new markets or countries with sizeable income, total income growth in markets with innovation projects), eco efficiency data (when projects with eco-innovation aims concur): data of carbon print evolution, recycling of materials data evolution, renewable energy data evolution, waste and hazardous waste production evolution and management data.

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VISUALIZING THE SOCIAL STRUCTURE OF ORGANIZATIONAL KNOWLEDGE LOSS (OKL): A BIBLIOMETRIC ANALYSIS

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ABSTRACT: Organizational Knowledge Loss (OKL) is a significant concern for companies as the loss of knowledge and experience can hinder progress and innovation. This study aims to understand the social structure of OKL. For this purpose, a bibliometric analysis consisting of performance and science mapping analyses was conducted. The results indicate different patterns of influence and cooperation, with Durst emerging as the most influential author. In addition, institutions such as University of Skövde, the University of Hong Kong, Northwestern Polytechnical University, Asian Centre for Organisation Development, and Southwest Jiaotong University are central to promoting cooperation between different research institutions. Understanding the dynamics of research collaboration networks and the role of individual researchers and institutions is crucial for shaping the landscape of knowledge production and dissemination. Future research should consider additional aspects, such as the conceptual and intellectual structure of OKL research. This will allow a more coherent picture to emerge.

KEY WORDS: *Organizational Knowledge Loss; Bibliometric Analysis; Social Structure.*

1. PURPOSE OF THE PAPER

This study attempts to gain a comprehensive understanding of the research landscape and collaborative efforts in the field of OKL by investigating the social structure of the field. The following research questions guide this study:

- *RQ1. What is the local impact of authors in the OKL field?*
- *RQ2. What patterns can be identified in research collaborations among authors in the OKL field?*
- *RQ3. What patterns can be identified in research collaborations among institutions in the OKL field?*

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2. RELATED WORK

OKL is an issue of increasing importance that has been examined extensively in recent literature because of its potentially detrimental effects on organizations (Daghfous et al., 2023; Durst and Zieba, 2019; Galan, 2023; Massingham, 2018; Zieba et al., 2022). Durst and Zieba (2019) define it as a circumstance in which "an organization loses a part or all of its crucial knowledge" (p. 8). OKL can be driven by various factors, including employee turnover, retirement, inadequate documentation, and ineffective knowledge sharing within an organization (Daghfous et al., 2023; Durst and Zieba, 2019; Galan, 2023). The implications of OKL can be severe, leading to diminished efficiency, stifled innovation, increased costs, and a loss of competitive advantage (Daghfous et al., 2023; Galan, 2023; Massingham, 2018).

3. METHODOLOGY

In this study, we conducted a bibliometric analysis, combining performance and science mapping analyses, to investigate the local impact of authors and the social structure in the OKL field. We identified articles on management and economics indexed in the Social Sciences Citation Index (SSCI) of the Web of Science (WoS) and combined them with listed articles in Scopus journals to form a dataset. We then used OpenRefine to clean the data, remove irrelevant articles, and address missing or inconsistent data (Ham, 2013). This process yielded a refined corpus of 146 articles. This final dataset included articles published between 2004 and 2023. The articles were analyzed using Biblioshiny, a powerful bibliometric software tool that facilitates the visualization and evaluation of various bibliometric indicators (Aria and Cuccurullo, 2017).

4. FINDINGS

4.1 RQ1: Authors' local impact

Table 1 assesses the authors' local impact based on their h-index, g-index, m-index, total citations, number of publications, and publication year start. The metrics show that three researchers have a high local impact. These include Durst, a researcher from the University of Skövde, Sweden, and Fawad and Naiding, researchers from Northwestern Polytechnical University, China.

Starting in 2012, Durst has an h-index of eight, signifying that at least eight of her publications have been cited at least eight times each (Hirsch, 2005, p. 16569). Her g-index of nine suggests that the top nine works have been collectively cited at least 81 times, indicating a strong influence (Egghe, 2006, p. 132). The m-index of 0.73 highlights her consistent research output, producing, on average, 0.73 highly cited works per year since the start of her career (Hirsch, 2005, p. 16571). Her work has been cited 292 times, and she has published nine papers.

Having started in 2020, Fawad made noteworthy strides with an h-index of three and a g-index of four, respectively, demonstrating that his research is gaining recognition in the scientific community. He consistently produced, on average, 1.00 highly cited works per year (m-index of 1.00), and his work has been cited 20 times in total. Fawad has four publications in his name.

Naiding, also starting in 2020, has an h-index and g-index of three, suggesting that his work is gaining traction in the academic community. His m-index of 1.00 indicates a steady output of highly cited works per year. His research has been cited 19 times, and he has published three papers. These achievements highlight the influence and productivity of Durst, Fawad, and Naiding in their respective research fields. The citations indicate that their work has had an impact and is well-regarded within the scientific community.

Table 1. Authors' Local Impact.

Element	h-index	g-index	m-index	TC	NP	PY_start
Durst S.	8	9	0.727	292	9	2012
Fawad S. S.	3	4	1.000	20	4	2020
Naiding Y.	3	3	1.000	19	3	2020
Zieba M.	3	3	0.500	101	3	2017
Sumbal M.	3	3	0.500	63	3	2017
Tsui E.	3	3	0.500	63	3	2017
Massingham P.	3	3	0.200	167	3	2008
Ibrahim R.	3	3	0.188	57	3	2007
Bruns G.	2	2	0.333	18	2	2017
Casey A.	2	2	0.250	43	2	2015

Note: TC = Total citations, NP = Number of publications, PY_start = Publication year start.

4.2 RQ2: Network visualization of author collaboration

Figure 1 shows a scientific map of author collaboration divided into ten clusters. It can be observed that the individual nodes vary in size. Thus, large nodes are observed in the blue, red, and brown clusters, indicating a high collaboration density.

The blue cluster includes such distinguished researchers as Durst, Zieba from Gdansk University of Technology (Poland), Bruns from University of Iceland (Iceland), Wilhelm from University of Liechtenstein (Liechtenstein), and Ali from King Abdulaziz University (South Arabia).

The red cluster encompasses respected authors, such as Sumbal, Tsui, and See-to from the Hong Kong Polytechnic University (China), Shujahat from the University of Hong Kong (China), and Ali from National University of Sciences and Technology (NUST, Pakistan).

Finally, the brown cluster houses distinguished authors Fawad and Naiding on the one hand, and on the other hand, Rehman from Asian Centre for Organization Development (Pakistan) as Kanwal from Southwest Jiaotong University (China).

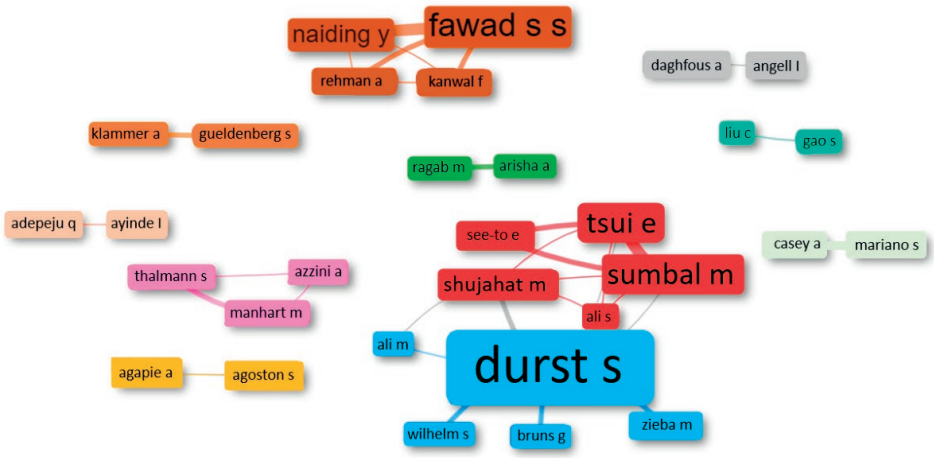

Figure 1. Network Visualization of Author Collaboration.

Table 2. provides an analytical snapshot of author collaboration dynamics in the OKL field using network metrics, such as betweenness centrality, closeness centrality, and PageRank.

Betweenness centrality represents a metric that emphasizes a node's capacity to act as an information intermediary among distinct clusters of nodes. An augmented value suggests that an author is pivotal in interconnecting researchers from disparate groups (Donthu et al., 2021, p. 290). Durst stands out with the highest betweenness centrality score of 23, while Sumbal and Tsui also make considerable contributions, both holding a score of 3.5.

Closeness Centrality is an indicator that gauges the adjacency of a specific node in relation to other nodes within the network, with superior scores suggesting an author's proficiency in effectively propagating knowledge to other authors in the network (Donthu et al., 2021, p. 291). In a remarkable collaboration display, Fawad, Naiding, Kanwal, and Rehman all share the maximum closeness score (0.33).

Finally, PageRank analysis can identify the prestige of publications within a network based on highly cited publications (Donthu et al., 2021, p. 291). A higher score suggests a more significant influence within the network, with Durst securing the top spot with a PageRank score of 0.08, closely followed by Sumbal and Tsui, each with a score of 0.05.

Table 2. Network Metrics for Author Collaboration in the OKL Field.

Node	Cluster	Betweenness	Closeness	PageRank
Durst S.	Blue	23	0.100	0.078
Ali M.	Blue	0	0.059	0.016
Zieba M.	Blue	0	0.056	0.016
Bruns G.	Blue	0	0.056	0.016
Wilhelm S.	Blue	0	0.056	0.016
Sumbal M.	Red	3.5	0.077	0.046
Tsui E.	Red	3.5	0.077	0.046
Shujahat M.	Red	2	0.077	0.038
Ali S.	Red	0	0.071	0.026
See-To E.	Red	0	0.050	0.025
Fawad S. S.	Brown	0	0.333	0.044
Naiding Y.	Brown	0	0.333	0.032
Kanwal F.	Brown	0	0.333	0.027
Rehman A.	Brown	0	0.333	0.027

4.3 RQ3: Network visualization of institution collaboration

Figure 2 shows a visual representation of institutional cooperation in seven clusters. To the node's size, the two most collaborative clusters are red and purple.

The red cluster encompasses institutions such as University of Skövde (Sweden), Gdansk University of Technology (Poland), the University of Hong Kong (China), University of Iceland (Iceland), National University of Sciences and Technology (NUST, Pakistan), and Tallinn University of Technology (Estonia).

In the purple cluster, Northwestern Polytechnical University (China), Asian Centre for Organization Development (Pakistan), and Southwest Jiaotong University (China) have found collaborative niches. The other clusters, including the blue cluster, exhibit collaboration between fewer institutions.

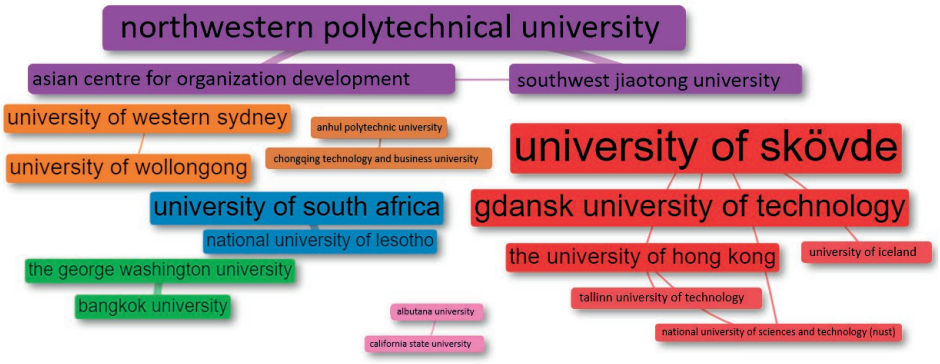

Figure 2. Network Visualization of Institution Collaboration.

Table 3 lists the social structure metrics of the clusters.

In the red cluster, University of Skövde stands out with the highest betweenness score (7), signifying its crucial function as a bridge within the network. The University of Hong Kong, another cluster member, also plays a vital role as a connector with a betweenness centrality score of 4. Despite the differences in their betweenness centrality, these institutions are critical in facilitating communication and collaboration within a cluster.

The purple cluster is noteworthy owing to its high closeness centrality. Institutions such as Northwestern Polytechnical University, Asian Centre for Organization Development, and Southwest Jiaotong University all exhibit a closeness centrality score of 0.50. This high score implies that these institutions are well-integrated and closely knit within their clusters, furthering internal collaboration effectively. In essence, while the nodes in the red cluster act as key connectors, facilitating the flow of information across different clusters, the institutions in the purple cluster are characterized by their solid internal connectivity. This distinction highlights the different roles of the institutions within an academic collaborative network.

Table 3. Network Metrics for Institution Collaboration in the OKL Field.

Node	Cluster	Betweenness	Closeness	PageRank
University of Skövde	Red	7	0.167	0.101
The University of Hong Kong	Red	4	0.143	0.076
National University of Sciences and Technology (NUST)	Red	0	0.125	0.051
Gdansk University of Technology	Red	0	0.100	0.029
University of Iceland	Red	0	0.100	0.029
Tallinn University of Technology	Red	0	0.091	0.029
Northwestern Polytechnical University	Purple	0	0.500	0.062
Asian Centre for Organization Development	Purple	0	0.500	0.048
Southwest Jiaotong University	Purple	0	0.500	0.048

5. RESEARCH LIMITATIONS

This study has three main limitations. First, restricting data acquisition to Scopus and WoS could limit the breadth of the research landscape. While these databases are reputable and widely used, relevant studies and data may be present in other databases or grey literature not included in this analysis. Second, the authors' and affiliated institutions' information may not remain current. Third, our study focuses solely on the social structure of OKL. While this provides crucial insights into collaboration networks and influential entities within the field, it does not capture other essential aspects, such as the conceptual or intellectual structure of OKL.

6. PRACTICAL IMPLICATIONS

When seeking collaboration opportunities, it is crucial to consider researchers with a proven record of productivity and influence, as demonstrated by Durst's impressive h-index and the g-index. Similarly, the rapid productivity growth of Fawad and Naiding implies that aspiring researchers can significantly contribute to research projects. The research community can use this knowledge to enter targeted collaborations with researchers and associated institutes, such as University of Skövde, Northwestern Polytechnical University, Asian Centre for Organization Development, and Southwest Jiaotong University.

7. ORIGINALITY

This study offers a novel examination of the research terrain in OKL by mapping social structure and accentuating the institutional networks and the impact of authors. A significant finding is the influential role of Durst and University of Skövde as central and well-connected entities within the OKL research network. Additionally, we noted the emergence of rising researchers, such as Fawad and Naiding, from Northwestern Polytechnical University. These findings underscore Sweden and China's central role in OKL research.

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THE ECONOMIC VALUE OF MUSIC: A LITERATURE REVIEW

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ABSTRACT: This work is based on the Horizon Europe project Music360 that will develop a platform to collect data to analyze and represent the value of music. The economic value of background music has been studied by the literature and different variables can be taken into account. In this literature review, we have explored which are these main variables that can help venues and stores to increase their incomes thanks to music, direct or indirectly. From the analysis, we can infer that the music genre, tempo, quality and volume, the size of the venue or store, the age or gender of the customer, the shopping spent time, the sentiment post-comments or the fit with the brand and product/service, can influence positively or negatively the customer experience and, hence, the expenditure and even the evaluation of the personnel. We can conclude that background music has shown relevant influence on the customer behaviour and, for this reason, it is important to match it with the best positive experience for the customer depending on the kind of venue or store and the products/services offered.

KEY WORDS: *Background music; economic value; venues; shopping; customer behaviour.*

1. INTRODUCTION

The purpose of this paper is to analyse the literature focused on the economic value of music in order to explore the variables that are related to customer behaviour. In many venues and stores, music plays a key role to stimulate the experience, emotions and feelings of the customers. The selection of genre and other attributes are sometimes underestimated by their managers, and for this reason we examine what the literature has tested on this topic.

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2. METHODOLOGY

We have performed two searches in Scopus database. In the first one, we use as keywords "value AND music", limiting the results from 2009 and selecting other specific keywords, which results in 723 records (Figure 1). This first figure helps us to observe which are the topics that have been studied in the last years and which keywords can accurate more the search. As we see on the right, music education was a main topic ten years ago but, at present, other topics such as music therapy or non economic value have also captured the attention of the authors.

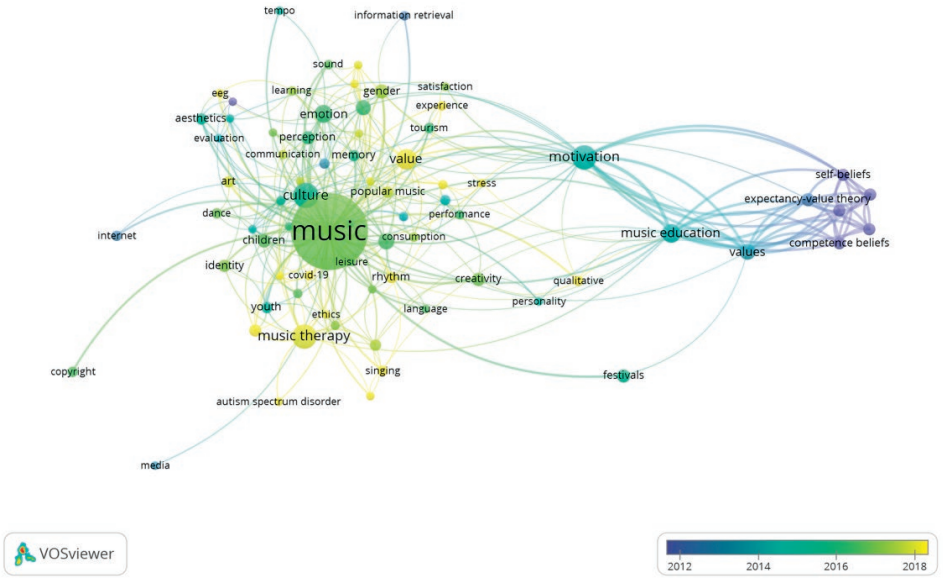

Figure 1. Co-ocurrences among keywords "value&music". Own elaboration.

Regarding the economic value of music, we noticed that papers were more focused on consumer behaviour and some of them referred to previous literature. Therefore, we made a second search in Scopus based on the keywords "value AND music AND behaviour", limiting the results from 2002 and those that involve "Humans" and "Controlled Study", as many of the papers were qualitative case studies. This search returned 218 papers (February 2023). Afterwards, using the software VosViewer (Van Eck and Waltman, 2020), we observe the co-occurrences among the terms in order to establish if there is a relationship among 61 relevant keywords agreed among the research group. Then, from the visualized clusters, we select a group of papers to apply content analysis (Elo and Kyngäs, 2008) and extract the variables related to the economic value of music.

3. FINDINGS FROM THE LITERATURE REVIEW

As we can observe in Figure 2, different clusters show keywords co-ocurrences, where the colour of an item is determined by the cluster to which the item belongs (Van Eck and Waltman, 2020). For our purpose, not all of them are relevant as we focus on stores and venues. For example, music therapy and related topics are the most studied by the literature but they are out of our scope. We want to pay attention to emotions related to consumer but not to patient behaviour.

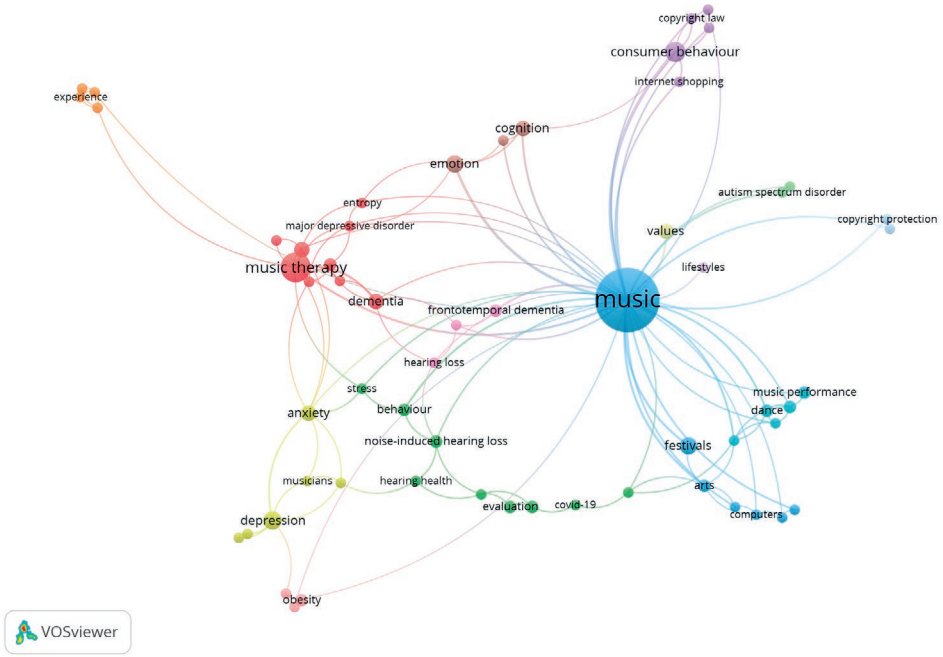

Figure 2. Co-ocurrences among keywords "value&music&behaviour". Own elaboration.

According to Lonsdale and North (2011), music is particularly important for adolescents and young adults, but less important for participants aged over 30. This selection is also reflected on their expenses, while young adults (25-29) spend the most money each month on music, participants aged 50 years and over spend the least on music each month. By gender, men 25-29 years and over 50 years report spending more money on music than women of a similar age.

Regarding the economic value of music, papers related to venues normally pay attention where life music is played, and in this sense the effects of music are easier to analyse because their target is already known as well as the genre played. For example, listening to a classical music concert has a specific target. For venues,

Kruger and Saayman (2017) highlight economic value also post-event because participants could return, comment on it positively, recommend it to others and/or create awareness and appreciation of a specific music genre (and buy that music).

Other situation could be background music listened in stores. In this occasion, depending on their size, small and big stores have different music interaction with their customers. Music can have different results on consumer behaviour, emotional responses, temporal effects and spending patterns.

The literature has explored how in small stores it is easier to fit the background music with the product/service and/or the brand image for having a certain impact. For Jacob et al. (2009), background music must be appropriate for the context in which it is employed in order to enhance persuasion for shopping, but in itself does not encourage customers to spend more money, this would be an indirect effect. Background music is considered as congruent with a product if a rationale or symbolic information is connected with the product being sold.

Other authors even demonstrate that, if there is congruence between the background music and the products on offer, there could be a positive attitude toward sales personnel and store evaluation.

In the case of big stores, the literature analyses background music as part of the experience to spend more time and, indirectly, to spend more money. For Vida et al. (2007), shopping time and expenditure increase with the level of preference for the background music, regardless of the tempo or volume. But in big stores with task-oriented shopping environments (i.e. supermarkets), the effect of background music on store evaluation is lower because they offer fewer opportunities for interaction with store personnel.

Anyway, recent studies are more focused on digital music. Kim et al. (2009) explain that, while shopping online, background music has less effect on consumers' emotional responses. And Sirkeci and Magnúsdóttir (2011) describe that buyers evaluate better digital music stores than downloaders rate illegal downloading. Moreover, the quality of music files is perceived to be 15 per cent more satisfying in digital music stores than on illegal channels.

4. IMPLICATIONS AND LIMITATIONS

After this first literature review, we can gather different variables that are important to take into account when selecting background music for an indirect effect on shopping and, therefore, analyse the economic value of music in stores. These variables are: the shopping spent time, the fitting of the music with product/service, the genre, the tempo, the volume and the influence on customer emotions. Specially, they are important in small stores where the impact of background music could be higher than in big stores, not only in terms of expenditure but even for the evaluation of the personnel.

In venues, the age or gender of the customer are crucial. Also, the sentiment post-comments can influence positively or negatively the customer experience.

Finally, we can infer that the quality of music is the most important variable in digital music.

5. PRACTICAL IMPLICATIONS

To retain shoppers in their facilities, stores should carefully select background music to closely match tastes and preferences of their core customers. Moreover, background music should be chosen through consumer research, and not according to personnel preferences.

6. CONCLUSIONS

With this paper we have started to concrete the variables that are significant to study the economic value of music, especially background music in stores. But, in the case of venues, the literature is more focused on life music. This analysis shows us a literature gap for future research on the impact of background (life) music in events, where music is not the principal activity (for example, a popular festival), taking into account that they have been less studied by the literature.

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AUTHOR CONTRIBUTIONS

M. De Miguel: Conceptualization, Original draft, Methodology; B. De Miguel: Investigation, Visualization; D. Catalá: Formal analysis; C. Carrascosa: Data curation; O. Pastor: Supervision and G. Giachetti: Review & Editing.

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DATA VISUALIZATION – THE EFFECT OF GRAPH ANIMATION ON PERSUASIVENESS

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ABSTRACT: To make data visualization more attractive, not just color or different shapes are used, but also animations are nowadays added to graphs. Software tools for data visualization use different representation styles or display features and include animation in the data visualization process. Until now, the positive effect of different representation styles has been taken for granted in practice. However, this raises the question of the extent to which such representation styles are effective and what results can be seen in research in this regard. A literature review on data visualization is given to examine this in more detail. It was considered to what extent there are already findings on whether animated graphs have an effect on consumers' behaviors. In the following work, we mean by an animated graph, a graph that is not visible from the beginning. Instead, the graph builds up over time. This way, motion is added to the graph. The literature review shows that data visualization has been studied more frequently in some areas. In marketing, this has received less consideration so far. Animations in graphs have not been studied much in the literature.

KEY WORDS: *Animation; Persuasiveness; Data Visualization.*

1. INTRODUCTION

In the era of big data, various visualization formats for the large amount of data are very common and often used. There is different software for data visualization with diverse representation styles (Camm et al., 2017; Caughlin & Bauer, 2019; Ertug et al., 2018). The representation styles can vary in several attributes. These attributes must be specified when creating data visualization, especially graphs. One of these attributes can be the display mode. The display mode of a graph can be animated or static. In a static graph, no additional motion is added to the graph. It is like an image, and all the information is fully visible from the beginning as soon as the graph is displayed. There are several ways how animation can be added to a graph. In this work, an animated graph is defined as a graph

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to which motion has been added. The graph is not fully visible at the beginning. Instead, it builds up first and is fully visible only after a certain time (J. Kim & Lakshmanan, 2021; J.A. Schwabish, 2014; Zhuang & Liu, 2022). An animated graph can show the change in data over time (S. Kim et al., 2007). Other than an interactive graph, an animated graph does not allow manipulation of the data points by the viewer (J.A. Schwabish, 2014).

Apart from business contexts, graphs are also used in the everyday life of consumers. They are, for example, very important in news reporting to show election results, unemployment rates, or the latest mood barometers. These graphs are increasingly used in animated format nowadays. Instead of being just static, motion is added to the graph. Animated graphs are also sometimes used on social media platforms, for example, to inform the public (Ancker, 2020).

The presentation of data to consumers is for many companies already very common (Wandel, 1997). Non-profit organizations use visualized (static) data to encourage consumers to donate or to convince other stakeholders of their goals (Waters, 2007). But also, companies in the beauty or health industry use data to persuade consumers of the benefits of a product and to make them buy their products (Peters et al., 2007; Schwartz et al., 2007). However, as far as is known, companies have not yet widely used animated graphs in their marketing campaigns.

This paper aims to provide an overview of the state of the literature on data visualization. The main objective is to analyze the extent to which this topic has already received attention in marketing and in relation to the consumer. Furthermore, it will be examined to what extent the graph attribute animation has already been investigated.

2. RESEARCH BACKGROUND AND RESEARCH QUESTIONS

2.1 Literature results on data visualization in general

Visualization is, in general, a function that displays one or more types of data (nominal, ordinal, interval, ratio, absolute) mapped to a shape or color (Chakrabarty & Mendonça, 2010). There are different definitions of data visualization. It can be defined as the "science of the visual representation of data" (Bačić & Fadlalla, 2016, p. 78) and refers to the "visualization or representation of raw data" (Tay et al., 2018, p. 664). Data visualization is a "computer-supported visual representation of data that allows users to select the information they wish to view, and its format is an important tool for achieving this objective" (Dilla et al., 2010, p. 1). For this work, data visualization is thus defined as the graphical mapping of data (nominal, ordinal, metric) with different types of representations. This mapping should help users to select and understand relevant pieces of information. The various visualization formats should support this process.

There are a lot of different types of data visualization. The most common data visualization types are area charts, bar/column charts, line charts, pie charts, radar charts, pareto charts, maps, scatter plots, venn diagrams, and tables (Bajić et al.,

2019; Bajić & Job, 2021; Savva et al., 2011). Subcategories like donut charts, grouped or stacked bar charts, or box plots can be assigned to one of the categories (Bajić et al., 2019). There is a lot of research on the comparison of tables versus graphs (Benbasat & Dexter, 1985, 1986; Davis, 1989; DeSanctis, 1984; Frownfelter-Lohrke, 1998; Jarvenpaa, 1990; Jarvenpaa & Dickson, 1988; Lucas, 1981; MacKay & Villarreal, 1987; Remus, 1987; Vessey, 1991). Therefore, tables are separated from the other graph types in this work, like in previous studies. The different graph types can be separated between those with and those without a Cartesian coordinate system (Bajić & Job, 2023). It must be noted that graphs and graphics are not the same in this work. By graphics pictorial representations are meant.

"The first general principle in data visualization is that design and layout matter. The design and layout, including the type of chart or table used, should draw attention to the parts of the visualization that are important in conveying your message to your intended audience" (Camm et al., 2017, p. 474). The presentation format has an impact on consumers' information acquisition strategy. Graphs contain much information that needs to be understood by consumers. Therefore, the presentation format of the information must facilitate processing (Bettman & Kakkar, 1977). Visualizations help to present data more interestingly and to understand complex data easier (Archambault et al., 2015). Thereby, not only single graphics are used but also non-static or interactive representations (Bendoly, 2016). Data presented as graphs can look and be interpreted very differently depending on the scaling of the graph and its compression or elongation (Lurie & Mason, 2007). In addition, certain visualizations are often misunderstood and misinterpreted (Bendoly, 2016), or data are displayed in such a way that viewers automatically interpret them in the desired direction (Glazer et al., 1992; Jarvenpaa, 1990; Lurie & Mason, 2007). Thus, the first general principle of data visualization of Camm et al., (2017) is often not followed. Data visualization should therefore support the viewer's understanding and not overwhelm him. The animation could help reduce consumer overwhelm when viewing a graph and guide the viewing of the graph.

Since the 1980s, there has been a lot of research on data visualization and how to present data in the best possible way. In the area of accounting and management, there is much research comparing tables versus graphs and which visualization is best in which situation (Benbasat & Dexter, 1985, 1986; Davis, 1989; DeSanctis, 1984; Frownfelter-Lohrke, 1998; Jarvenpaa, 1990; Jarvenpaa & Dickson, 1988; Lucas, 1981; MacKay & Villarreal, 1987; Remus, 1987; Vessey, 1991). There are no consistent results across the different studies as to whether a table or a graph is better. Some studies show that there is no difference between tables and graphs (Benbasat & Dexter, 1985, 1986; Frownfelter-Lohrke, 1998; Jarvenpaa & Dickson, 1988), according to others, graphs are better than tables (Benbasat & Dexter, 1986; Cardinaels, 2008; Davis, 1989; DeSanctis & Jarvenpaa, 1989; Jarvenpaa & Dickson, 1988; Wright, 1995), and still other results say that tables are better than graphs (Benbasat & Dexter, 1986; Davis, 1989; DeSanctis, 1984). Other findings show that the effects vary according to the moderators (Benbasat & Dexter, 1985; DeSanctis, 1984; Lucas, 1981; MacKay & Villarreal, 1987; Remus, 1987; Vessey, 1991).

In marketing, research has so far not paid much attention to data visualization, especially not to graph animation. Research in this area is primarily limited to new visualization techniques (Klemz & Dunne, 2000; Ringel & Skiera, 2016), a literature review (Lurie & Mason, 2007), and one article on animated graphs (J. Kim & Lakshmanan, 2021). Following on from J. Kim and Lakshmanan (2021), animated graphs should be considered more deeply in marketing. This type of display mode has been studied little overall. Furthermore, when animations are considered, different types of animations are used than in this work.

2.2 Literature results on animation

Data that could be used for animated graphs is primarily time-varying data. Literature on how to present this data is mostly about static displays of financial data and decision-making (Bačić & Fadlalla, 2016; Benbasat & Dexter, 1985, 1986; Cardinaels, 2008; DeSanctis, 1984; Dilla et al., 2010; Duclos, 2015; Frownfelter-Lohrke, 1998; Jarvenpaa, 1989; Kelton et al., 2010; J. Kim & Lakshmanan, 2021; MacKay & Villarreal, 1987; Raghubir & Das, 2010).

In the literature, the use of animated and static graphics in the learning context has shown different results so far (Boucheix & Schneider, 2009; Dindar et al., 2015; S. Kim et al., 2007; Tversky et al., 2002). Meta-analysis has been conducted to better assess the effect of animated graphics. These have shown that animation often positively impacts learning (Berney & Bétrancourt, 2016; Höffler & Leutner, 2007). Animation can help to recognize trends in data. Studies that address this issue focus on outcomes like response times or error rates (Farrugia & Quigley, 2011; Robertson et al., 2008). There is literature on static versus dynamic node-link diagrams to illustrate the relationship between data points over time (Beck et al., 2017). It has also been observed that process models are better understood through animations that subjects could interact with (Aysolmaz & Reijers, 2021; see Table 1). How graph animations affect consumers has not yet been considered. Therefore, the usage of animation should also be applied to the presentation of data to consumers.

Table 1. Overview of sources on animation.

Author(s) (Year)	Animation	Dependent Variables	Hypotheses/ Research Questions
Graph Animation			
Aysolmaz and Reijers (2021)	Static vs. animated process models	Comprehension (test scores)	- Users of animation for process model visualization will have a higher comprehension performance than users of static process model visualizations. - The effect of animation on process model comprehension will differ according to the process modeling expertise of a user. - The effect of animation on process model comprehension will be greater for users with low expertise than those with a moderate level of expertise. - The effect of animation on process model comprehension will be greater for users with high expertise than those with a moderate level of expertise.

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Author(s) (Year)	Animation	Dependent Variables	Hypotheses/ Research Questions
Beck et al. (2017)	Animated node-link diagrams timeline-based dynamic approaches	State-of-the-art in visualizing dynamic graphs	- Build a hierarchical taxonomy of dynamic graph visualization and classify existing techniques into the taxonomy. - Applications for dynamic graph visualization approaches. - Bibliographic analysis of the collected publications reveals key topics and emerging trends. - Identify challenges for future research. - Feedback from the research community, based on questionnaires of experts in the field.
Farrugia & Quigley (2011)	Static vs. animated network images	Reaction time Error rates	- Hypothesize that animation will be beneficial, therefore (a) faster and (b) more accurate, in analyzing network overview tasks without time constraints. - Hypothesize that animation may be beneficial, therefore (a) faster and (b) more accurate, for tasks that require the user to follow a node throughout the network. - For localized tasks constrained by time, the overhead of interaction with the video for searching, stopping, and pausing might result in animated presentations constrained by time being (a) slower than static versions. The interaction overhead however should not impact the (b) accuracy of the results. - Hypothesize that the average response time will be (a) faster and (b) more accurate in lower-density networks than in higher-density networks.
J. Kim and Lakshmanan (2021)	Graph animation of line graphs and bar graphs	Risk judgments	- Risk judgments are greater when time-varying data are presented in an animated (vs. static) mode. - The salience of temporal transitions is greater when time-varying data are presented in an animated (vs. static) mode. - Temporal transitions are more likely to be utilized to infer risk when time-varying data are presented in an animated (vs. static) mode. - The salience and utilization of temporal transitions mediates the impact of animated display on risk judgments. - The effect of animated (vs. static) display on risk judgments through salience and utilization of transitions manifest with line graphs but attenuate with bar graphs. - The effect of animated display on risk judgments is attenuated in the presence of a global upward trend (but not in the presence of a global downward trend). - The effect of animated display on risk judgments is attenuated when investment goals reduce the association of transitions with risk (i.e., the effect will manifest for long-term but not for short-term investors).

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Author(s) (Year)	Animation	Dependent Variables	Hypotheses/ Research Questions
Robertson et al. (2008)	Gapminder Trendalyzer: Animated bubble chart	Reaction time Error rates	- Animation will be more effective than other techniques when used for presentation and less effective than other techniques when used for analysis. That is, participants will be (a) faster and (b) make fewer errors in the presentation condition. - Traces will be more effective than Animation when used for analysis. That is, participants will be (a) faster and (b) make fewer errors in the traces condition. - Small multiples will be more effective than animation when used for analysis. That is, participants will be (a) faster and (b) make fewer errors in the small multiples condition. - Participants will be more effective with small datasets than with large datasets. That is, participants will be (a) faster and (b) make fewer errors when working with small datasets
Learning			
Berney and Bétrancourt (2016)	Static vs. animated graphics displays of instructions (no graph)	*Meta-analysis learning outcome:* Knowledge Remember Understand Apply Analyze	- Are multimedia instructional materials containing animations overall beneficial to learning compared to static graphics display? If so, for which learning outcomes? - How are the animation effects influenced by factors related to the instructional material, such as the control over the pace, the function of the animation, the modality of the verbal commentary, and the type of animation media? - How do the animation effects vary according to the instructional domain of the content to be learned?
Boucheix and Schneider (2009)	Static vs. animated presentations user-control of an animated presentation (no graph)	Comprehension	- The presentation of integrated sequential static images describing a dynamic process and facilitating the elaboration of the mental representation of the movement led to a similar performance in a comprehension test as an animated presentation of the same process and to a higher performance than the presentation of sequential independent static images or a single static image. - Higher comprehension of the functioning of the mechanical system in the two controllable presentations as compared to the non-controllable.
Dindar et al. (2015)	Static vs. animated graphics (no graph)	Response time Response accuracy	- What is the difference between the response time of students who take the achievement test with static graphics and those who take the achievement test with animated graphics? - What is the difference between the response accuracy of students who take the achievement test with static graphics and those who take the achievement test with animated graphics?

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Author(s) (Year)	Animation	Dependent Variables	Hypotheses/ Research Questions
Dindar et al. (2015)	Static vs. animated graphics (no graph)	Response time Response accuracy	- What is the difference between the self-reported CL scores of students who take the achievement test with static graphics and those who take the achievement test with animated graphics? - What is the difference between the secondary task scores of students who take the achievement test with static graphics and the students who take the achievement test with animated graphics? - What is the relationship between response times, response accuracy, self-reports, and secondary task scores?
Höffler and Leutner (2007)	Static vs. animated pictures (no graph)	*Meta-analysis learning outcome:* Declarative Knowledge Problem-solving knowledge Procedural-motor knowledge	- Are animations better than static pictures in general? - Are representational animations better than decorational animations? - Are animations better for acquiring procedural-motor knowledge rather than declarative knowledge or problem-solving knowledge? - Are computer-based animations better than video-based animations? - Can static pictures be improved?
S. Kim et al. (2007)	Static vs. animated graphics displays of a bicycle pump (no graph)	Comprehensibility Interestingness Enjoyment Motivation Comprehension test	- Are there effects of animated graphics on comprehension, ratings of interestingness, and motivation to learn? - Are there interactions between the presentation mode of the learning material and the NFC of the learner? - Are there any developmental differences in comprehension, interestingness, and motivation as they respond to various types of graphic presentation?
Marketing			
Cian et al. (2014)	Logo dynamism	Attitude toward the brand	- A logo that evokes greater perceived movement (logo dynamism) generates more favorable attitudes toward the brand unless the perceived movement is incongruent with the brand characteristics. - The impact of logo dynamism on attitudes toward the brand is mediated by engagement.
Cian et al. (2015)	Icon dynamism	Perceived movement Vigilance Early Attention Reaction time Behavioral consequences Perceived risk	- A warning sign icon (e.g., a yield sign) with more (vs. less) perceived movement will attract earlier attention. - A warning sign icon with more (vs. less) perceived movement will evoke greater attentional vigilance. - A warning sign icon with more (vs. less) perceived movement will result in a faster reaction time. - A warning sign icon with more (vs. less) perceived movement will result in earlier stopping behavior (i.e., the stopping will occur farther back from the sign).

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Author(s) (Year)	Animation	Dependent Variables	Hypotheses/ Research Questions
Goldstein et al. (2014)	Animated Ads	Annoyingness ratings Website abandonment Distraction	- What is the economic cost of annoying ads to publishers? - What is the cognitive impact of annoying ads?
Jia et al. (2020)	Animation in video ad vs. static images of the video ad	Perceived product size Perceived distance Perceived quality Perceived durability Perceived reliability Perceived aesthetics Willingness to pay	- Consumers assess the size of a product to be smaller when the product is animated to move faster in a video ad. - The speed-based scaling effect is reduced for consumers who perceive low similarity of movement patterns between the focal product and the base domain of animate agents. - The speed-based scaling effect is reversed when consumers learn a positive association between body size and movement speed in the base domain of animate agents. - The speed-based scaling effect is reduced for consumers with more knowledge about the target product domain. - The speed-based scaling effect is reduced when explicit product size information is highlighted in video ads. - When a small product size is desirable, a faster animated movement speed leads to a higher willingness to pay than a slower animated movement speed. - When a large product size is desirable, a faster animated movement speed leads to a lower willingness to pay than a slower animated movement speed. - Size assessment mediates the effect of animated movement speed on willingness to pay.

Research in marketing on the effect of animation on consumers is primarily focused on advertising and does not include graphs. The results show that originally static advertising is increasingly shown in animated format. Banner ads online and other online display ads often contain videos or other forms of animation, and outdoor advertising is also increasingly dynamic instead of static (Goldstein et al., 2014; Jia et al., 2020). When logos or signs express a movement, more attention is paid to them, leading to a better attitude towards a brand or a faster response to the signs (Cian et al., 2014, 2015).

J. Kim and Lakshmanan (2021) are one of the first to investigate the effects of animated versus static graphs in a marketing journal. Therefore, this investigation is essential for the present work and will be considered intensively. They tested animation as a salience-inducing mode of displaying time-varying data (see Figure 1). Transitions in graphs on stock prices are noticeable through animations. Temporal variations are emphasized more than in static diagrams, where attention is to be drawn by, i.e., visual elements such as color or arrows (J. Kim & Lakshmanan, 2021). Animation enhances the salience of transitions. This increases the usage of transitions in forming risk inferences

and enhances risk judgments. The effect of animation only occurs with line graphs, not with bar graphs. Only for a downward trend the perception of risk is higher because of the salient animation. When the investment goal is long-term, risk judgments rise, and the investment amount lowers. For short-term investments, animated display does not increase risk judgments, and more is invested as a result (J. Kim & Lakshmanan, 2021).

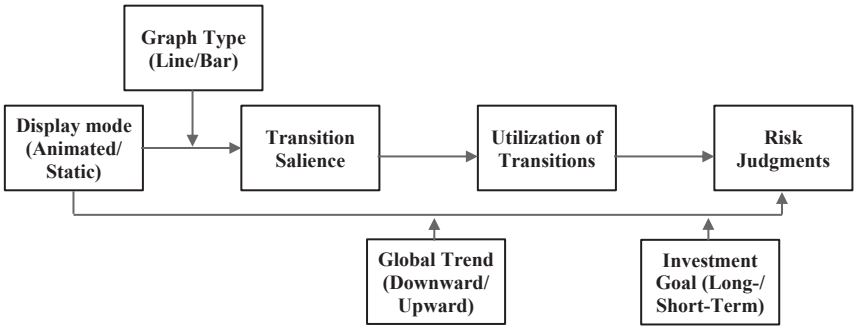

Figure 1. Summary of the theoretical framework of J. Kim and Lakshmanan (2021, p. 5).

J. Kim and Lakshmanan (2021, p. 3) "propose that animated display of a data string draws viewers' attention in real-time to the moment-to-moment unfolding of the data string". They use attention as an explanation but then attribute the actual effect to the salience of the transitions. They focus on risk judgments and investment amounts. According to their results, the salient transitions in animated graphs are used for making risk judgments. To find out, participants were explicitly asked about transitions, and one study measured what participants used to make their judgments. Thus, participants explicitly thought about the transitions and used them as explanations.

In their study, J. Kim and Lakshmanan (2021) look at the effect of animated graphs. Thereby, they focus on the effect of animated graphs on the risk judgments of managers. The effect of animated graphs on consumers is not yet investigated. In addition, the question still arises what happens subconsciously when subjects are not explicitly asked about the transitions in graphs? Depending on the focus area, animation can trigger different psychological mechanisms (J. Kim & Lakshmanan, 2021). Can animation be the reason why a graph triggers something in the consumer and is therefore effective? Consideration should be given to the mechanism behind the salience. How can animated graphs be used suitably? Can the more vivid visualizations cause a higher persuasiveness of a message?

As one moderator variable J. Kim and Lakshmanan (2021) look at the graph type (line vs. bar) and the overall trend of the graph (downward vs. upward). The effect of other graph attributes should also be investigated. Furthermore, participants have been told that they must make financial judgments. Financial judgments are made very thoughtfully and

consciously. Therefore, one might expect different results in other contexts. What happens if there are no noticeable transitions? What is the reason for the effects discovered by J. Kim and Lakshmanan (2021)?

It has already been shown that animated graphs can change judgments and decision-making compared to static graphs (bar/line) (J. Kim & Lakshmanan, 2021). No other dependent variables have been considered yet with these types of graphs. Other literature on animation focuses on investigating specific visualization tools like animation as the transition from one graph type to another (Heer & Robertson, 2007). Beck et al. (2017) only look at static versus dynamic node-link diagrams. Robertson et al. (2008) investigate bubble charts, which are animated in one condition, and participants can interact with the graphs. No other graph types are studied in these articles. As considered in this work, graphic animation has not been investigated extensively yet. In addition, other processes and outcomes than judgments, recall, reaction time, and the effects of animated graphs on decision-making have not been considered (Farrugia & Quigley, 2011; J. Kim & Lakshmanan, 2021; Robertson et al., 2008). Therefore, other dependent variables should be considered, and how animated graphs can affect consumers compared to static graphs. They could be the impulse needed to change consumer persuasion, leading to a change in attitudes and beliefs.

However, the question arises in which marketing contexts the effects of animated graphs for presenting data should be studied and where they might help better communicate information to consumers. Fifty years after the publication of "Marketing's Changing Social/Environmental Role" in the Journal of Marketing, "better Marketing for a better world" topics should be given a central position in marketing scholarship (Chandy et al., 2021). Marketing should make an impact on the world (Chandy et al., 2021). Social marketing is used to achieve this impact in the world. "Social marketing is the adaptation of commercial marketing technologies to programs designed to influence the voluntary behavior of target audiences to improve their personal welfare and that of the society of which they are a part" (Andreasen, 1994, p. 110). The target and intention are to persuade others to change their behavior, attitudes, and ideas or to select messages which influence these (Fogg, 1998; Nowak & Siska, 1995; Stewart, 2014). "Problems of pollution control, mass transit, private education, drug abuse, and public medicine are in need of innovative solutions and approaches for gaining public attention and support" (Kotler & Zaltman, 1971, p. 11; see Fox & Kotler, 1980). Animated graphs could be an approach to gain attention for these problems. Therefore, the effect of animated graphs should be investigated in such contexts.

3. METHODOLOGY AND OBJECTIVES

To see what has been studied so far on the topic of data visualization and animated graphs we conducted a literature review. In doing so, we searched for journal literature using the key words "Data Visualization" and "Animated Graphs" as well as their synonyms. We have limited ourselves to the subject areas that are linked to the economic sciences.

These are Accounting, Management, Marketing, Computer Science, Information Science and Education Science. In addition, only literature that matches the presented definition of data visualization was considered. An exception was the literature on animated graphs, since graphics were also considered here.

The aim of this work is to examine the extent to which data visualization has been considered in the literature to date and what results have emerged. In particular, the focus is on the communication of data to the consumer and thus on marketing. As a property of graphs, their animation will also be examined in more detail, since this is being used increasingly in practice. In practice, it should be known how to use graphs and especially animated graphs appropriately and how they may help to persuade consumers about a topic. Knowing when to use animated graphs instead of static graphs is relevant.

4. CONCLUSION AND PLANNED NEXT STEPS

As the review of the literature has shown, the effect of animated graphs on consumers has not been studied so far. To address the research questions identified, the next step is to conduct a study. We would like to examine the effect of animated graphs on consumers. Our question is whether the message of a graph is more persuasive when it is animated than when the graph is static. In the process, quantitative, experimental, primary data will be used. Therefore, participants will complete an online programmed questionnaire. The sample will primarily consist of students from the Ansbach University of Applied Sciences. Participants will be shown a graph about a health, social, or ecological issue. When using statistical evidence, negative framing of a cause is more persuasive than positive framing (Das et al., 2008). Therefore, the stimuli will be negative framed data about a social marketing topic. They will then be asked how persuasive the message of the graph was and what their attitude towards the topic is after seeing the graph. In the process, they will see either an animated or static graph.

This research will help to understand the reason for the effect of animated graphs. It will show if an animated graph catches more attention and is therefore more effective. Understanding this can help graphs in distracting environments to be more noticed and thus their content to be more involved by consumers in their decisions and actions.

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CONFLICT OF INTERESTS

No potential conflict of interest was reported by the authors.

AUTHOR CONTRIBUTIONS

Hoffmann, Franziska: Conceptualization; Methodology; Writing - Original Draft, Resources, Writing - Review & Editing. Sauer, Sebastian: Supervision. González-Ladrón-De-Guevara, Fernando: Supervision, Review & Editing.

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USING LSTM-PREDICTED STOCK PRICES AND RISK-ADJUSTED PERFORMANCE METRICS TO OPTIMIZE PORTFOLIOS IN THE EUROPEAN STOCK MARKET

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ABSTRACT: Long Short-Term Memory (LSTM) neural networks allow to capture long-range dependencies and non-linearities in sequential data and can learn complex patterns and relationships in the data improving the accuracy of future stock price predictions. Since classical portfolio optimization is highly sensitive to the estimated parameters used to construct an optimal portfolio, the purpose of our research is to leverage LSTM abilities to predict the parameters accurately and create portfolios that generate superior results. We predict the prices of the 50 components of the EURO STOXX 50® Index using LSTM and create prediction-based optimal portfolios for ten different investment time horizons. We define the risk as a combination of the standard deviation and the performance of the evaluation metrics obtained testing our model, allowing us to use a measure for the risk based on the level of confidence the model has in the prediction. Our portfolios consistently beat the market over the analyzed investment scenarios from 2021 until the first half of 2022 and are robust for both growing and bear markets. The proposed model achieves an average MAE of 0.01634, an average MSE of 0.00047, and an average accuracy of 95.8% in predicting the direction of the stock movements over the ten proposed periods. Our research contributes to the field of finance by providing an innovative framework for portfolio optimization that leverages the power of LSTM-based stock price prediction and risk-adjusted performance metrics.

KEY WORDS: *Long Short-Term Memory; neural networks; Eurostoxx50; portfolio optimization; risk-adjusted performance metrics.*

1. INTRODUCTION

Anticipating the movements of financial markets is a complex problem that makes it challenging for investors to optimize their portfolios and achieve their investment objectives. Classical portfolio optimization has a significant drawback related to its sensitivity to input parameters. It implies that the weights assigned to the different assets that make up the portfolio will vary depending on the estimation of the returns, variance,

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and covariance (Michaud & Michaud, 2008; Kolm et al., 2014). Consequently, there is a need for advanced techniques that can improve the accuracy and robustness of portfolio optimization methods while mitigating the limitations of classical portfolio optimization methods.

The increasing computing power has facilitated the efficient processing of large amounts of financial data, thereby enabling the use of artificial intelligence algorithms in predicting stock prices and optimizing portfolios.

The purpose of this research is to estimate the returns of the 50 stocks that compose the EURO STOXX 50® Index by using Long Short-Term Memory (LSTM) neural networks to create optimal portfolios based on a blended measure that combines the classical risk-return optimization with evaluation metrics of the model's performance, considering the confidence in the model's predictions during the asset selection process. In other words, we predict the price of the shares and then optimize portfolios based on LSTM-predicted prices. Our portfolios comprise the stocks with a better risk-return-performance, where the estimation errors are considered in the portfolio selection, assessing the problem of estimating the inputs.

This approach has two significant advantages. On the one hand, it allows us to reduce the error in estimating the input parameters of the portfolio optimization problem using advanced techniques such as LSTM neural networks. On the other hand, by including the predictive errors in the objective function to create optimal portfolios, the reliability of the prediction is considered in the selection, reducing the allocation of resources in stocks with less accuracy in the estimation of the parameters.

This paper aims to contribute to the existing literature by exploring the combination of the prediction of the price of the components of the main European market using LSTM and the optimization of prediction-based portfolios using the predictive error covering 2021 and 2022, which implies a period of continued growth but also bear markets.

2. LITERATURE REVIEW

In recent years, the use of machine learning techniques in portfolio optimization has gained significant importance from investment managers and academic researchers in the financial sector.

Portfolios created based on classical mean-variance optimization do not perform well with unknown data. This is caused by the estimation error of the mean and covariance matrix used as inputs, primarily due to the estimation of the sample mean (DeMiguel & Nogales, 2009). Due to the importance of the estimation risk in the creation of optimal portfolios, many authors have considered the incorporation of the estimation errors of the expected returns to create robust portfolios (Ceria & Stubbs, 2006; Gregory et al., 2011; Zymler et al., 2011; Fliege & Werner, 2014).

Machine learning algorithms can provide more accurate predictions than conventional techniques. Several studies have investigated the use of different artificial intelligence techniques, such as support vector machines, genetic algorithms, or neural networks, to predict stock prices (Alizadeh et al., 2011; Huang, 2012; Ticknor, 2013; Patel et al., 2015; Ma et al., 2021). Also, some authors have compared machine learning algorithms with traditional techniques, showing that recurrent neural networks outperform traditional methods, such as ARIMA, AR, or MA, in the prediction of time series (Ruis et al., 1998; Ghiassi et al., 2005; Adebiyi et al., 2014).

In addition, other authors have combined and compared artificial intelligence algorithms with conventional models. For instance, Kim & Won (2018) combined LSTM neural networks with GARCH models. Then they compared the result with GARCH models, which evidenced that the hybrid model performed better regarding the error metrics.

LSTM neural networks have demonstrated the ability to learn patterns and make predictions when using time series or sequential data as inputs, overcoming some of the drawbacks presented by recurrent neural networks (RNN), such as exploding or vanishing gradients or the ability to model long-term dependencies in sequences (Hochreiter & Schmidhuber, 1997; Hochreiter, 1998; Hochreiter et al., 2001). A comparison between LSTM and RRN was published by Lee & Yoo (2020). Their study, conducted on a specific set of 10 stocks from the S&P500, revealed that the LSTM model demonstrated superior performance compared to the RNN model regarding the hit ratio of 1-month ahead forecast.

Du (2022) conducted a study that focused on the S&P500 and CSI 300, where he applied several machine learning algorithms to predict the return of stocks. The LSTM presented the best performance in terms of predictive errors compared to the rest of the algorithms. The author constructs a portfolio that includes estimation errors in the objective function.

3. METHODOLOGY

3.1 Data and data treatment

This study focuses on the 50 stocks that compose the EURO STOXX 50® Index, representing the 50 largest companies in the Eurozone in terms of free-float market cap. Our research uses the data available from Yahoo! Finance. Specifically, we use daily closing prices from 2015 until the first half of 2022, implying 1903 trading days.

Considering that the EURO STOXX 50® Index comprises companies from several countries and not all of them entered the index on the same date, the trading days are not homogeneous, and the stock components present some missing values. These missing values are dropped before training the LSTM. In addition, before starting the training process, we use Min-Max Scaler to transform the values between 0 and 1 and apply a rolling window of 42 days. Therefore, the model is trained considering that the

42 consecutive trading days used as input have the 43rd day as output, representing around two months of trading. We trained the model using several rolling window sizes, but a window of 42 days provided better results than the others.

Table 1 illustrates the rolling window input-output sequence used (Jansen, 2020).

Table 1. Rolling window sequence.

Input	Output
($x1$, $x2$,…,$x41$, $x42$)	($x43$)
($x2$, $x3$,…,$x42$, $x43$)	($x44$)
⋮	⋮
(xT-42, xT-41,…,xT-2, xT-1)	(xT)

We split the resulting dataset into training and test data based on the year. The model is trained with closing prices that cover until the end of 2020 and tested with closing prices from 2021 until the 30th of June. This split allows us to test the ability to predict prices unknown by the model.

3.2 Long Short-Term Memory

We use Long Short-Term Memory neural networks since their ability to capture long-range dependencies and non-linearities in sequential data improves the results in the prediction of stock prices.

The LSTM was trained during 500 epochs using early stopping to avoid overfitting, with a batch size of 50 and a learning rate of 0.001, and the hyperparameters were fine-tuned. The resulting architecture of the LSTM is composed of two layers. The first layer contains 40 hidden units; the second layer is a regular dense layer of 1 unit. Despite training with other topologies that are more complex, the results did not improve significantly.

To avoid vanishing gradients, we use tanh as the activation function, sigmoid as the recurrent activation function, and RMSprop as the optimizer (Hinton et al., 2012). Also, the loss function, the function that the model will try to minimize during the training, that we use is Mean Squared Error (MSE) since it is widely used for regression problems (Hastie et al., 2009).

We calculate the returns for ten different investment strategies covering 2021 and the first half of 2022 using the predicted prices. First, we focus on 2021, when the market experienced continuous growth, where we define five different investment strategies based on the time the stock is held, being approximately 1, 3, 6, 9, and 12 months holding the stocks. Second, we cover the first half of 2022, the worst first half of the market in the last 50 years. For this period, we define five strategies of 25, 50, 75, 100, 127 days holding the stocks. We assume that the investor buys the stocks on the first day of the

year for both periods, implying a fixed starting point for the different holding periods. Equation (1) presents how the predicted returns ($\hat{r_t}$) are calculated, where $\hat{P}_t$ and $\hat{P}_{t-1}$ are the predicted price at time t and t-1, respectively.

$$\hat{r}_t = \frac{\hat{P}_t - \hat{P}_{t-1}}{\hat{P}_{t-1}} * 100 \tag{1}$$

The metrics considered to evaluate the prediction are the MSE and the Mean Absolute Error (MAE), both shown in equations (2) and (3), respectively, and where r_t is the real return. In addition, the accuracy of the model predicting the direction of the movement of the stock price is calculated following equation (4), where TP, TN, FP, and FN are the true positive, true negative, false positive, and false negative values, respectively.

$$MSE = \frac{1}{n}\sum_{t=1}^{n}(r_t - \hat{r}_t)^2 \tag{2}$$

$$MAE = \frac{1}{n}\sum_{t=1}^{n}|(r_t - \hat{r}_t)| \tag{3}$$

$$accuracy = \frac{TP + TN}{TP + TN + FP + FN} \tag{4}$$

3.3 Risk-Adjusted Performance Metrics Portfolio Optimization

In order to perform the portfolio optimization problem, we need to calculate the portfolio's expected return and the risk, which are based on the prices predicted by the LSTM. The expected return of the portfolio with N stocks is the weighted average of each stock and is presented in equation (5), where $\hat{r_i}$ is the LSTM predicted return of the stock i and W_i is the percentage of available resources allocated to stock i.

$$\hat{r}_p = \sum_{i=1}^{N} \hat{r}_i \times W_i \tag{5}$$

In the calculation of the risk of the portfolio, we propose the blended Error-Risk measure that combines the Mean Squared Error obtained by the model for each stock as a performance metric and the volatility calculated as the classical risk measure in portfolio optimization. The calculation is shown in equation (6), where MSE_i is the Mean Squared Error of the stock i, W_i and W_j are the stocks i and j weights, and γ_{ij} is the covariance. *Metrics_Weight* and *Classical_Risk_Weight* are used to weigh the two components in the equation.

$$\widehat{ER}_p = Metrics\_Weight \times \left(\sum_{i=1}^{N} MSE_i \times W_i\right) + Classical\_Risk\_Weight \times \sqrt{\sum_{i,j=1}^{N} W_i\, W_j\, \gamma_{ij}} \tag{6}$$

In the portfolio optimization model, we aim to maximize the Sharpe Ratio, calculated using the metrics mentioned above, and the risk-free rate r_f, which is 0.0106 due to the value of the 3-month US Treasury bill as of May 2022.

The portfolio optimization model that we proposed is presented below. The objective function (7) is the predicted Sharpe Ratio, with the Error-Risk adjusted performance metric considered as the denominator. The model is subject to several constraints. Equation (8) guarantees that the return is higher or equal to the return of the risk-free investment. Equation (9) guarantees that the sum of all the individual weights allocated to the stocks equals 1, meaning that all the available budget is invested. Equation (10) ensures that individual weights of the stocks are non-negative to avoid the possibility to short-sell assets and represent less than 45% of the portfolio to guarantee that at least three stocks should be selected.

$$\text{Maximize} \quad \widehat{SR} = \frac{\hat{r}_p - r_f}{\widehat{ER}_p} \tag{7}$$

$$\text{Subject to} \quad \sum_{i=0}^{N} \hat{r}_i \times W_i \geq r_f \tag{8}$$

$$\sum_{i=1}^{N} W_i = 1 \tag{9}$$

$$0.45 \geq W_i \geq 0, \qquad i = 1, 2, \ldots, N \tag{10}$$

The portfolios are constructed for the ten holding periods considered in the prediction of prices and compared against the EURO STOXX 50® Index, which is used as the benchmark, allowing us to have an objective reference of the performance of the portfolios created and to evaluate if active is worth it compared to passive investment.

4. FINDINGS AND VALUE OF THE PAPER

The results of our research shed light on the effectiveness of the proposed approach in portfolio optimization. We can achieve several milestones using Long Short-Term Memory neural networks to predict stock prices and the posterior incorporation of predictive errors in the objective function.

First, using Long Short-Term Memory neural networks, we can accurately predict the stock price of EURO STOXX 50® Index components. The prediction is tested for the ten investment strategies for 2021 and the first half of 2022. The predictive errors are displayed in Tables 2 and 3. The average MSE and MAE of the considered holding periods are 0.00047 and 0.01634, respectively. The average accuracy is 95.8% in predicting the direction of the stock's movements.

These findings regarding the predicted returns align with the existing literature in the field. We achieve comparable or even superior results compared to other studies (Sadaei et al., 2016; Weng et al., 2018; Wang et al., 2020; Ma et al., 2021; Du, 2022).

Table 2. Predictive performance for the different holding periods – Year 2021.

Performance metric	Holding period (days)				
	20	63	125	191	255
Mean Squared Error	0.000282	0.000315	0.000567	0.000506	0.000607
Mean Average Error	0.014035	0.011952	0.016857	0.017717	0.016256
Accuracy (%)	92	96	94	96	98

Table 3. Predictive performance for the different holding periods – Year 2022.

Performance metric	Holding periods (days)				
	25	50	75	100	127
Mean Squared Error	0.000733	0.000274	0.000296	0.000539	0.000541
Mean Average Error	0.023118	0.013162	0.013619	0.018037	0.018692
Accuracy (%)	90	100	98	94	100

Second, constructed portfolios based on LSTM-predicted data and optimized using the blended Error-Risk measure are tested using real data. We use the weights allocated to the different stocks selected in the portfolio based on predicted returns to calculate the real returns of the portfolio. The results show that our optimized portfolios can obtain positive returns and persistently beat the benchmark. These results are consistent for both analyzed periods, showing that our results are robust and independent of the direction of the market. Despite that the EURO STOXX 50® Index went down by more than 20% in the first half of 2022, our portfolio achieved almost 15% of return. These results are presented in Figure 1, where the analyzed holding periods are compared against the benchmark.

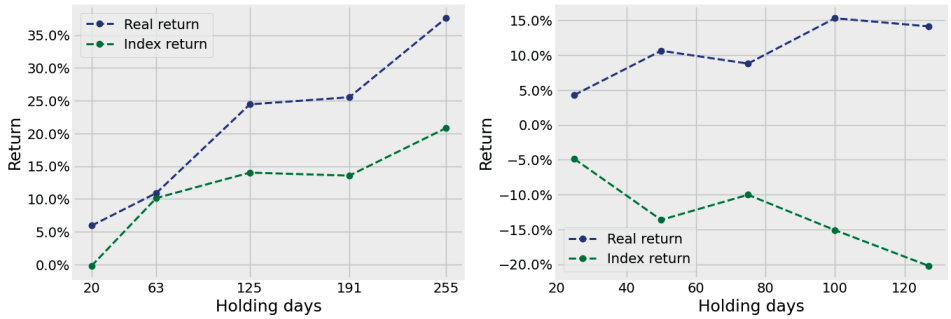

Figure 1. Real return of the portfolio compared to the return of EURO STOXX 50® Index – Year 2021 (left) and 2022 (right).

5. RESEARCH LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

Even with the achieved results, this paper has certain limitations. The prediction relies only on historical prices, disregarding news, macroeconomic aspects, or fundamental indicators. Our approach considers a strictly technical perspective, assuming prices comprehensively reflect all relevant information.

For future research, we could consider fundamental or technical indicators to complement the input of the neural network and use transformers to improve the performance of the predictions. Also, other techniques could be used to optimize the portfolios, such as reinforcement learning or quantum-inspired algorithms.

6. PRACTICAL IMPLICATIONS

Since we focus on European public markets, asset and portfolio managers or individual investors could use the current research to support them in making investment decisions or automating their investments. In addition, using algorithms to select assets reduces the subjective factor and avoids decisions driven by irrational emotions.

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CONFLICT OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHOR CONTRIBUTIONS

Martínez-Barbero, X. Conceptualization, Methodology, Software, Writing - Original Draft, Writing - Review & Editing. Cervelló-Royo, R. Methodology, Writing - Original Draft, Writing - Review & Editing, Supervision. Ribal, J. Conceptualization, Writing - Original Draft, Writing - Review & Editing, Supervision.

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REAL ESTATE MEETS TECHNOLOGY. THE IMPACT OF NEW TECHNOLOGIES ON THE REAL ESTATE SECTOR IN SPAIN

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ABSTRACT: The real estate industry has traditionally been a low-tech industry. The arrival of new, more technological companies in the sector has brought about a revolution in an industry that is very conservative and not very innovative. The term *Proptech*, short for property technology, groups together new activities that include applications, platforms and, in general, technologies related to the digitalization of the real estate sector. It includes core technologies of the Industrial Revolution 4.0. such as Big Data, Artificial Intelligence, Blockchain, visualization technologies, the Internet of Things and cloud computing; technologies that are rapidly changing how the agents involved, buyers, sellers, investors, managers or tenants, operate. Due to the large number of activities and technologies involved, there needs to be some clarification about the scope of activities and technologies within *Proptech*. This paper explores the different classifications and maps of *Proptech* in Spain. The objective is to provide knowledge regarding the composition and delimitation of the *Proptech* sector in Spain and its comparison with the classifications made in other countries. To do this, an adaptation of the *Proptech* map of Spain will be made with the categorization created by Baum (2017, 2020) in which four large clusters or groups of activities are identified: Real Estate Fintech, Shared Economy, Smart Real Estate and Data Digitalization and Analytics.

KEY WORDS: *Proptech; Real Estate Fintech; Shared Economy; Smart Real Estate.*

1. INTRODUCTION

The term *Proptech* derives from the union of "property" and "technology". It includes all products, processes and business ideas that apply the most innovative resources of information and communication technologies (Tagliaro et al., 2020).

Proptechs are those companies or startups that, using the latest technology, are able to improve and optimize the processes of investment, management, construction and

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marketing of real estate assets.[1] There needs to be some clarification about the scope of activities and technologies within *Proptech* due to the sheer number, diversity and complexity of these. The paper explores the different classifications and maps of *Proptech* in Spain with the aim of clarifying its structure and composition. After consulting several international classifications, we start from the categorization made by Baum et al. (2020) of the Saïd Business School of Oxford University, in which four clusters of activity are identified. From here, each of the categories of the Spanish *Proptech* map is identified with the clusters identified by Baum. The aim is to provide information to be able to assess the composition and evolution of *Proptech* in Spain compared to other countries.

2. CONTEXT

Proptech is defined as the mass deployment of emerging technology in the real estate sector. "PropTech is one small part of the wider digital transformation of the property industry. It describes a movement driving a mentality change within the real estate industry and its consumers regarding technology-driven innovation in data assembly, transactions, and the design of buildings and cities" (Baum and Dearsley, collected in Davenport, 2017). According to these authors, *Proptech* is, on the one hand, a name that defines all technological innovations in the real estate segment and, on the other hand, the industry itself, the business sector. It is also a collective term used to identify start-ups that offer technologically innovative products and new business models for real estate markets (Siniak et al., 2020).

The report 2023 European *Proptech*: 32 countries in numbers & UAE[2] by *Proptech* Bulgaria indicates that on 1st February 2023, the total number of *Proptech* companies is 9641; in Europe, the number rises to 4775 companies, and in Spain, the *Proptech* ecosystem has 554 companies, which represents a weight of 11% of the total number of European companies. According to the report, Europe accounts for 50.24% of the total number of *Proptech* companies, followed by North America with 24.69% and in third place Asia Middle East and Pacific where the proportion of companies is 13.81%.

The *Proptech* sector encompasses a variety of real estate-related businesses, from property management, through financial services, insurance, maintenance, and facilities, ranging from marketing platforms, shared use, real estate management, financial services, transactions, construction, data exchange, maintenance and facilities management services. The great diversity of activities makes the term complex and difficult to delineate. In recent years, several maps have been constructed to identify the main areas that are identified (Tagliaro et al., 2020).

Alongside *Proptech*, there are other tech sectors, such as *ConTech*, the technology sector that supports all dimensions of the building process, from design to construction. *LegalTech*, based on the use of smart contracts and facilitating transactions and especially

[1] https://propertytechnology.es/empresas-proptech-mapa/

[2] http://proptechbulgaria.eu/2023-european-proptech-32-countries-in-numbers

Fintech, is a combination of "financial technology", the new technology that seeks to improve and automate the delivery and use of financial services. The term *FinTech* is conceived as the implementation of the use of new technologies and disruptive business models in the field of financial services (World Economic Forum, 2015). As noted by Baum et al. (2020), *Fintech* includes a broad spectrum of activities, including *Lending tech*, *Payments/Billing tech*, *Institutional/Capital market tech*, *Equity Crowfunding*, *Insurtech*, and *Personal Finance*. Many of these new technologies also affect the real estate sector, in fact, many companies included in the above *Fintech* fields operate in the real estate market. Between the financial and real estate sectors, there are areas of activity in common that are called *Real Estate FinTech* (Valín, 2020).

3. PROPTECH CLASSIFICATION

After analysis of various corporate reports, it can be determined that *Proptech* is any digital innovation that affects the real estate sector, so it is a very broad concept (Valín, 2020). "The non-exhaustive list of these technologies includes home search tools, drones, virtual reality, building information modelling (BIM), data analytics tools, artificial intelligence (AI), Internet of Things (IoT) and blockchain, smart contracts, crowdfunding in real estate, financial technologies related to real estate (fintech), smart cities and regions, smart homes and sharing economy" (Siniak et al., 2020).

The literature review points to two main approaches to identifying *Proptech* areas. On the one hand, classifications are made on the basis of a deductive method and, on the other hand, the categorization of the sector following an inductive method (Tagliaro et al., 2020). According to Jacob (2004), the classification is done on the basis of predetermined guidelines or principles and through a scheme that is artificial and arbitrary, "[...] artificial because it is a tool created for the express purpose of establishing meaningful organization; and arbitrary because the criteria used to define the classes in the scheme reflect a single perspective of the domain to the exclusion of all other perspectives." (Jacob, 2004). Categories are inferred from a creative synthetic process. Classes are derived from the literature and subsequently populated with entities (Tagliaro et al., 2020).

After reviewing the literature, the author establishes the following classification criteria: the technology used, the stages in the supply chain, the drivers of innovation and the stakeholders involved. Firstly, classifications based on technology often differentiate technology based on its state of evolution, *Proptech* 1.0, 2.0 and 3.0 (JLL, 2017; Baum, 2017). Secondly, the classification based on stages in the supply chain focuses on the types of production-related businesses by differentiating between pre-construction, construction and post-construction sectors (Maududy and Gamal, 2019). Thirdly, looking at the drivers of innovation, a distinction is made between information, transaction and management and control. We can consider three lines of action that guide *Proptech's* activities. Firstly, the possibility of accessing more information of higher quality and at a lower cost. Secondly, greater efficiency in operations by reducing time and costs and, thirdly, improving management processes such as valuations and asset

management (Baum, 2017). Another classification establishes the following drivers of innovation construction, operation, management, marketing and transaction (Maudududy and Gamal, 2019); Fourthly, if we look at stakeholders, they are grouped into capital investment activity, commercial market, building management and residential market (Shaw, 2018). On the other hand, Categorization is mainly based on types of activities or product functions. This approach has been proposed mainly by consulting companies, but also by researchers.

In Spain, Aguirre Newman created the first *Proptech* map, including 58 companies (InmoDiario, 2017). This first map identifies four categories: portals and marketplaces, P2P (peer-to-peer) technology solutions, virtual reality and collective investment or crowdfunding platforms, later expanding to 9 categories. Table 1 compares three classifications of *Proptech* in Spain based on technology. API's report *Radiografía del Proptech en España* raises the number of *Proptech* companies to 514 in 2022.

Table 1. Ranking of Proptech technologies in Spain.

	API (b)			
Aguirre-Newman and Finnovating (a)		nº companies	% companies	Dekker (c)
P2P, Peer to Peer	Peer to Peer	77	15.0%	Rental Peer to Peer
	Shared spaces	16	3.1%	
Real State Software	Software y CRM	74	14.4%	CRM, Property software
Big Data	Big Data	59	11.5%	Big data
Marketplaces	Webs and marketplaces	57	11.1%	Marketplaces
Visual Startups	Image	55	10.7%	Virtual Reality
Smartphone	Smartphone	45	8.8%	
Investment	Investment, buyers	35	6.8%	Crowdfunding
			0.0%	Agents & Buyers
	Property management	25	4.9%	Property management
Mortgage Financing	Mortgage	21	4.1%	Morgages
	Scoring	10	1.9%	
	Marketing	15	2.9%	Marketing
	Legal	13	2.5%	Legal
Home automation/smart homes/IoT	Smart offices	12	2.3%	Home automation Real Estate news Accelerators Aggregators Events Blockchain
	TOTAL	514		

Source: Own elaboration based on (a) Proptech map Aguirre-Newman and Finnovating (b) Radiografía del Proptech en España API (2022) (c) https://privacasa.eu/proptech

The professional organisation API *Colegios y Asociación de Agentes Inmobiliarios de Cataluña* have published the best-known *Proptech* map in Spain for several years. It was published for the first time in 2020, and its latest update in July 2023 includes 580 companies, see Table 2. In this map, companies are classified according to the services they provide, differentiating those that are more directly aimed at real estate professionals. On the one hand, 352 B2B and B2B2C oriented companies are identified and categorised according to the needs of the real estate business to which they provide solutions: Agency, Product and Clients. On the other hand, another 228 B2C and C2C companies were identified. In turn, each of these categories is composed of different types of technological solutions. Figure 1 shows each category's proportion over the total number of companies in the *Proptech* map.

Table 2. Proptech companies in Spain.

		B2B y B2B2C	B2C y C2C	Total
Legal	Your agency	12		12
CRM and Software		65	16	81
Digital signature		9		9
Platforms		12	2	14
Investment	Your customers	10	27	37
Funding		19	6	25
People Rating		10		10
Household management		19		19
Image	Your product	57	11	68
Attract		31		31
Smart spaces		15	5	20
Peer to Peer		16	42	58
Real State Valuation		30		30
Portal		41	26	67
Showcase		6		6
ibuyers			7	7
Smart homes			34	34
Property manager			9	9
Big Data			23	23
Shared spaces			20	20
		352	228	580

Source: API, Propteh Map, July 2023.

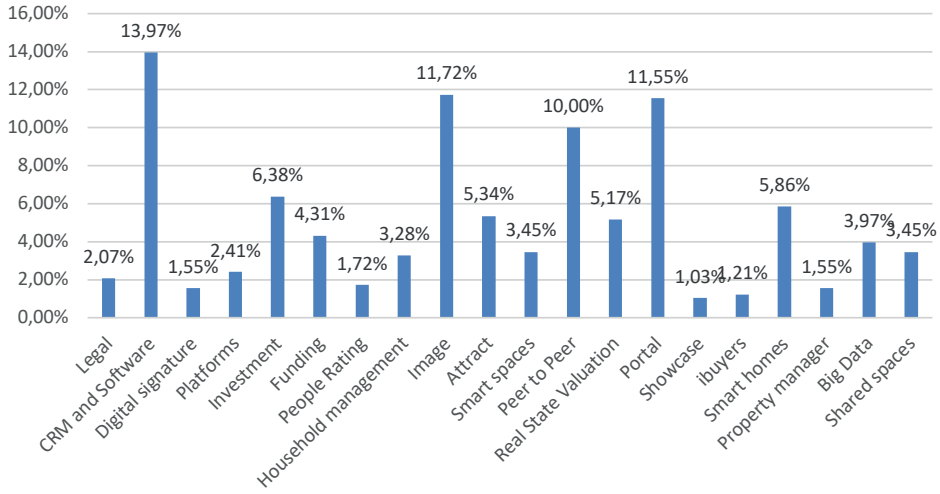

Figure 1. Share of Proptech companies in Spain by category, 2023.
Source: Own elaboration based on API (2023).

At the international level, among the different classifications analysed, the study by the University of Oxford stands out. In this classification, three drivers are identified from the point of view of innovation in the sector, known as horizontal drivers, namely information, transaction and management and control (Baun, 2017). A later report states, "The roots of PropTech lie in 5 areas or drivers: construction technology, legal technology, the shared economy movement, FinTech and exogenous technology" (Baum, 2020). Four clusters or areas of activity are established: Smart Real Estate, Real Estate Fintech, The Real Estate Shared Economy and Data Digitalization and Analytics (nuts and bolts), Baum (2020).

The Real Estate Fintech includes technology applications to facilitate transactions in real estate assets, whether real estate, real estate investment trusts, debt or equity. These are markets in which both ownership and leasing are transferred. Technologies will be geared towards improving the sector's critical aspects of profitability and efficiency, liquidity and transparency. Baum et al. (2020) point to three aspects that influence liquidity: the time it takes for the asset to be sold, the probability of the sale occurring, and the costs associated with the transaction. On the other hand, the greater the transparency, the more information participants can access that will allow them to trade more rationally. Various technologies aim to increase this transparency in a market that has traditionally been very opaque. Real Estate Fintech includes those FinTech technologies applied to the Real Estate sector. These include *LendingTech*, which includes platforms for peer-to-peer lending and solvency analysis; *Payments/billing tech*, which includes tools to facilitate invoicing and payments; *Personal finance/wealth management*, which includes technological tools aimed at facilitating wealth management for individuals; *Blockchain/token*, a technology that uses distributed databases, without a central manager, to register

and transfer assets using distributed databases maintained by users to register and transfer digital assets; *Capital Markets tech* on Investment, Crowfunding and *Insurtech*. In line with the innovation drivers mentioned above, Real Estate Fintech uses technologies for information and transactions (Baum, 2017, 2020).

Smart Real Estate describes technology-based platforms that facilitate real estate asset operation and management. The platforms may simply provide information, or they may directly facilitate or control building services. It uses technologies related to information management and control. Green initiatives, especially *Contech*, establish Smart Real Estate's origins. In the case of *Contech*, technologies related to prefabrication and especially Building Information Modelling (BIM) have been of significant influence.

The Shared Economy describes technology-based platforms which facilitate the use of real estate assets, land, and residential or commercial buildings. Platforms may simply provide information or facilitating transactions or effect rent- or fee-based transactions.

The fourth area of activity, Data Digitalization and Analytics, includes those technologies oriented towards data management, analysis and visualization that drive the digitalization movement. We include in this group Big Data, which provides software designed to analyse, process and extract information from extensive and complex data sets. We also include the development of technologies such as Blockchain.

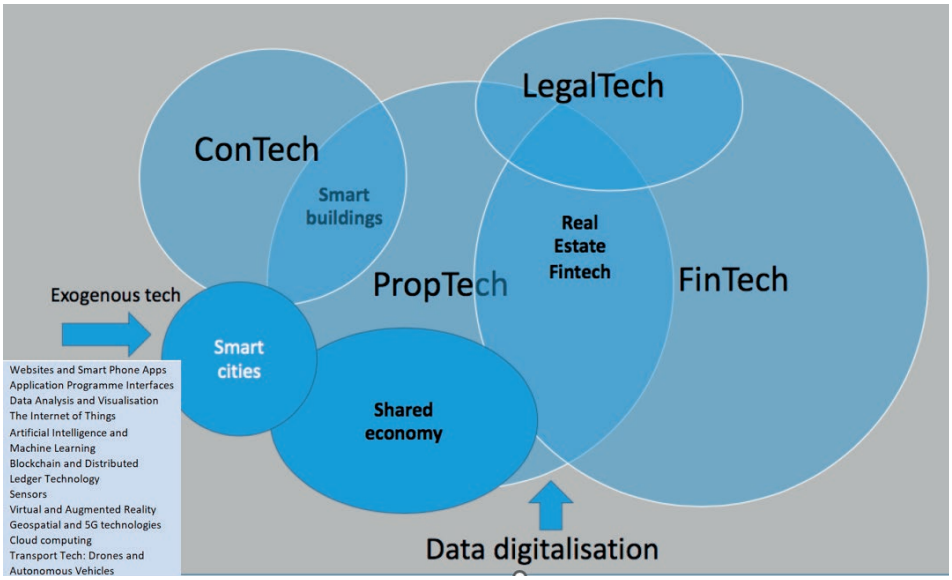

Figure 2. Branches of activity in Proptech.
Source: Baum (2020) and own elaboration.

Based on the categorisation made by Baum et al. (2020), see Figure 2, we integrate the categories of the *Proptech* map of Spain into this one, along the same lines as Tagliaro (2020) for *Proptech* in Italy. This will allow us to relate the sector's evolution with other countries more easily.

Table 3. Proposed categories based on the classification of Baum et al. (2020).

Proposed classes Baum (2020)	Proposed categories API
Context	Context
Smart Real Estate	Smart Spaces
	Smart Homes
	Image
	Household management
	CRM & Software
Real Estate Fintech	Property manager
	ibuyers
	Platforms
	Legal
	CRM & Software
	Digital signature
	Portal
	Investment
	Funding
	People Rating
	Attract
	Image
	Showcase
	Real State Valuation
Shared Economy	Peer to Peer
	Shared spaces
	Platforms
Data digitalization/analytics	Big Data

Source: Own elaboration.

4. CONCLUSION

Although the real estate sector has been characterized by being conservative in terms of the adoption of new technologies, recently and especially since the crisis resulting from the Covid-19 pandemic, the process of adopting technology and digitalization has accelerated significantly. Thus, *Proptech* has come to be known as the set of activities in which technology oriented towards the real estate sector is developed. The term comes from the merger of two other terms, "property" and "technology", and has followed a terminology similar to that of other sectors such as finance with *Fintech*, insurance with

Insurtech or construction with *Contech*, among others. Although it is widely accepted what is meant by *Proptech*, there is no clear consensus on the delimitation and classification of the activities that form part of it. It is a recent and rapidly developing phenomenon. This work has aimed to clarify the composition of the sector in Spain in order to facilitate its comparison with other countries. This last task will be carried out in future works.

Although the real estate sector has been characterized as conservative in terms of adoption. In the case of Spain, after the analysis of the different existing *Proptech* maps, the API map has been analyzed in more depth as it has a more complete trajectory and information.

When consulting the different classifications of *Proptech* at the international level that appear in the literature, the one carried out by the University of Oxford by Baum (2017 and 2020) stands out, which, beyond focusing only on the type of technologies applied, is oriented towards the search for clusters of activity. As in the case of other European countries, such as Italy, the work carries out an adaptation of the Spanish *Proptech* map with the classification proposed by Baum. This adaptation will allow a more in-depth comparison of the Spanish *Proptech* map with that of other countries.

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THE SOCIAL MEDIA HATE SPEECH BAROMETER: MAKING OF

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ABSTRACT: Hate speech, particularly on social media channels, is a pressing cybersecurity concern and can even threaten the very foundations of societal stability. While there is a growing body of literature on how to detect and mitigate hate speech, applied researchers lack a state-of-the-art yet easily accessible infrastructure to build their own hate speech detection pipelines. We aim to provide an example of such an infrastructure that can serve as a template for other researchers. The infrastructure we present is based on the latest machine learning technologies available in the R environment: The Tidymodels framework and its extension Tidytext, plus the Targets project management approach, are the building blocks of our proposed infrastructure. In short, our data pipeline starts with downloading and pre-processing tweets, using various methods to convert text into numerical information. We then apply state-of-the-art supervised machine learning pipelines, drawing on a range of learning algorithms and incorporating new tuning capabilities. The focus of this paper is to explain the setup and rationale of the infrastructure. Our infrastructure is freely available on Github at https://github.com/sebastiansauer/hate-speech-barometer.

KEY WORDS: *Hate speech; machine learning; cybersecurity; natural language processing; artificial intelligence.*

1. INTRODUCTION

According to the United Nations, "hate speech" can be defined as offensive discourse targeting a group or an individual based on personal characteristics such as race, religion, or gender.[1] The UN amends that hate speech may threaten social peace. Although there is a lack of a widely accepted definition, the UN proposes the following definition of hate speech:

> any kind of communication in speech, writing or behaviour, that attacks or uses pejorative or discriminatory language with reference to a person or a group based on who they are, in other words, based on their religion, ethnicity, nationality, race, colour, descent, gender or other identity factor.

[1] https://www.un.org/en/hate speech/understanding-hate speech/what-is-hate speech, accessed 2024-05-24

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Although hate speech is nothing new, it has been given a boost by the internet, which has made it possible for threats, conspiracies, and lies to travel quickly throughout the globe (Castaño-Pulgarín et al., 2021). Hate speech is having a visible impact on society: there are many commonalities between the January 2023 assaults on Brazil's government buildings,[2] and the attack on the US Capitol on January 6, 2021, including that each event happened after certain groups continuously used threatening language and false allegations against others. According to a BBC news article, online hate speech in the UK and US has risen by approx. 20% since the start of the Covid pandemic.[3] Given the surge of hate speech, defense mechanisms are on the rise too, albeit without being able to turn the tide, at least so far. For example, Iceland's government is the 34th to join ratification concerning the criminalization of acts of a racist and/or xenophobic nature committed through computer systems.[4] Some researchers have even put forward the hypothesis of a causal link between social media use and offline violence (Calvert, 1997; Chan et al., 2016; Cinelli et al., 2021). Carley (2020) summarizes that hate speech constitutes a major threat not only for democracy and civil rights including freedom, but also for individual mental and psychosocial health. For example, Wypych & Bilewicz (2022) conducted an online survey among N=726 Ukrainian immigrants living in Poland. The authors aimed at investigating the association between exposure to hate speech, stress, and mental health. They conclude that (prolonged) exposure to hate speech causes mental health problems of the target population. In sum, albeit a monetary or similar quantification is difficult, it can be concluded that hate speech is a substantial menace to society. It is the aim of the research presented in this paper to fight back hate speech by fostering research endeavors for detecting hate speech.

1.2 Related work

It is important to address hate speech to prevent violence against protected characteristics and to promote a safe and respectful online environment. However, setting limits on speech at a global scale in various languages and cultures is complex and identifying hate speech can be difficult in an online global community. One aspect that contributes to the difficulties in hate speech detection is that false negatives (missing hate speech) and false positive (false accusing of hate speech) are like Scylla and Charybdis, the opposing monsters of the ethical consequences of faults and shortcomings in such decision.[5] Augmenting the already high difficulties in detecting hate speech is that annotators are not necessarily reliable, and a universal definition of hate speech does not exist (as to yet).

Different methodologies for detecting hate speech have been developed and are in widely circulated use, comprising deep learning, shallow learning, and text-mining (non-machine learning) approaches. One basic text mining approach is a keyword-based

[2] https://en.wikipedia.org/wiki/2023_Brazilian_Congress_attack

[3] https://www.bbc.com/news/newsbeat-59292509, accessed 2024-05-24

[4] https://www.coe.int/en/web/cyberviolence/-/iceland-joins-the-first-additional-protocol-to-the-convention-on-cybercrime-on-countering-xenophobic-and-racist-acts-committed-through-computer-systems, accessed 2024-05-24

[5] cf. https://about.fb.com/news/2017/06/hard-questions-hate-speech/, accessed 2024-05-24

method, where an ontology or dictionary is used to identify text containing potentially hateful keywords (MacAvaney et al., 2019). However, simply using a hateful slur is not enough to constitute hate speech according to a study of different definitions of hate speech (MacAvaney et al., 2019). More advanced techniques include machine learning models ranging from word count methods (e.g., TFIDF) to complex BERT models (Jahan & Oussalah, 2021). Successful detection models use more than one approach, including hybrid models that combine different techniques for more accurate results (Alkomah & Ma, 2022). Advancements in natural language processing (NLP) and machine learning have greatly improved the detection of hate speech. With the help of machine learning algorithms, particularly deep neural networks, NLP can be used to identify linguistic patterns and features that are indicative of hate speech (Jahan & Oussalah, 2021; Pang, 2022; Velankar et al., 2022; Yin & Zubiaga, 2021). Various approaches have been used to detect specific features or linguistic patterns that denote hate speech in text, including rule-based classification models and, more recently, a proliferation of deep learning methods like Long Short-Term Memory networks and Transformer-based architectures (Malik et al., 2022).

Whereas hate speech detection is an active field of investigation, the border between hate speech and other forms of questionable social behavior is blurry. For example, bot detection is an emerging research (and engineering) branch that has sparked a substantial number of research activities. For a research overview, see Cresci (2020).

1.3 Methodology

Machine learning (ML) is often considered as a subset of artificial intelligence (AI). AI is a broad field that aims to emulate human abilities, while machine learning focuses on training a machine to learn and adapt through experience Bakshi & Bakshi (2018). ML constitutes the intersection between statistics and computer science, and its rapid progress have largely been driven by the ongoing reduction in computational costs (Jordan & Mitchell, 2015). In its score, ML is a new interpretation of the old quest of finding patterns in data. Correlations, which have been a subject of statistical studies at least since a century, are among the most prototypical examples of how patterns in data can be grasped. Once pattern have been found in the data, predictions can be inferred. The action of reducing a data set with many variables to a (potentially very) simple rule, is what has been dubbed a "model" (Stigler, 2016). In fact, the usefulness of a model hinges on its ability to be reductive. To be clear, there is not causal knowledge necessary for some model to predict some event, which probably fueled its widespread use given the fact that causal knowledge is very hard to gain and surpasses a purely statistically oriented research agenda (cf. Pearl, 2009). ML algorithms of the present day are highly flexible allowing to "fit an elephant", as von Neumann remarked to a similar matter.[6] On the pro side, highly flexible algorithms can pick up even minute and complex patterns in data, which may in some circumstances be useful, as many phenomena, particularly in

[6] https://math.stackexchange.com/questions/2970219/was-von-neumann-right-that-with-four-parameters-you-can-fit-an-elephant, accessed 2024-05-24

the social sciences, tend to behave in complex ways. However, there are drawbacks of highly flexible algorithms as well: Such algorithms tend to perceive signals where in fact there only is noise, a phenomenon well known as Pareidolia in perception research, and as overfitting in ML. To be fair, one may argue that human suffer from Pareidolia at least as much as machines do. However, countermeasures against overfitting are in place. Two common procedures are, described in high-level terms, (1) testing the model's predictions on new data, data unknown to the model, and (2) "prune" or "penalize" the model for complexity, to strike a balance between unnecessary complexity and exaggerated parsimony (James et al., 2021).

1.4 Purpose and value added of the paper

Given the social impact of hate speech and the vibrant advances in ML, applied researchers desperately need tools and templates to investigate social science research questions. Even without being experts in machine learning, social scientists need access to state-of-the-art tools. This research aims to support this by providing a template for hate speech detection. Our target audience is social scientists with intermediate technical knowledge in statistics and ML. Fortunately, typical ML pipelines, at least in their basic form, are quite mechanical and simple, and can therefore be automated quite easily. However, given the prosperity and rapid progress of ML, it would be inappropriate to provide polished point-and-click interfaces. Rather, script-based approaches to ML pipelines are advantageous because they can be quickly adapted to new developments. Indeed, most new developments in statistics and ML, at least in the last few years, have been in the R and Python programming languages. For this reason, we provide a template that makes use of the R language and its rich ecosystem of statistics and ML tools. Our aim is to make it easier for applied researchers in the social sciences to conduct their own hate speech analyses without having to worry too much about the intricate technicalities of ML.

2. RESEARCH DESIGN

This paper describes a tool that facilitates a classical ML pipeline focused on hate speech detection. The source code is freely available online.[7] To this end, we provide a typical ML pipeline, including well-known steps such as tuning different ML algorithms and applying resampling schemes. In addition, we have made use of GNU-Make-like project management tools to improve reproducibility and usability, see details below. The results of the analyses facilitated by this project could be summarized with plots such as Figure 1.

Next, we describe the design ideas of this project.

[7] https://github.com/sebastiansauer/hate-speech-barometer

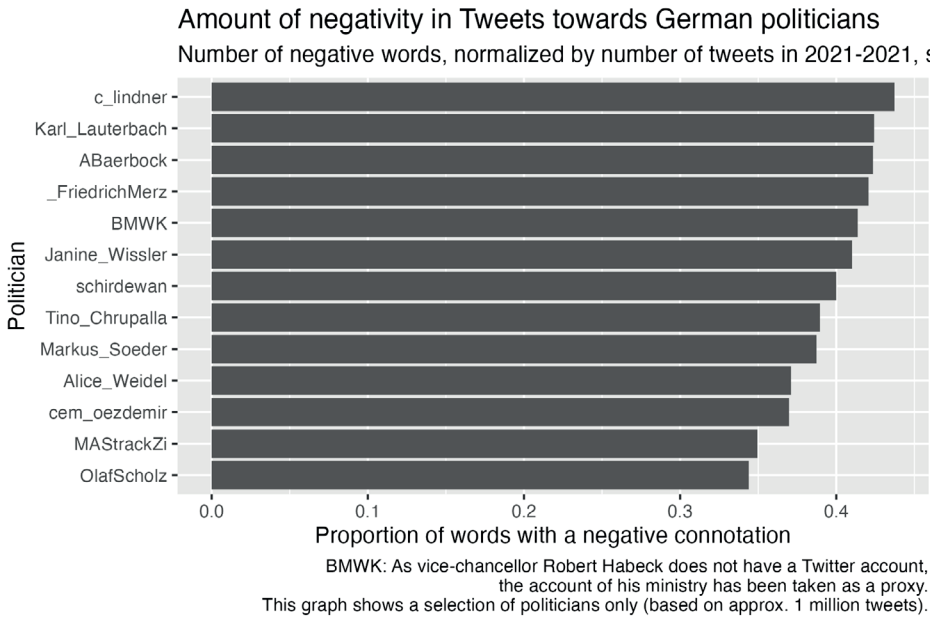

Figure 1. Hate speech proxies based on Tweets to German politicians.

2.1 Reproducibility

Reproducibility has been described as a hallmark of science (Plesser, 2018), and the present research builds strongly on this idea. Our analysis is based entirely on scripts that are freely available and licensed under the GNU General Public Licence. Git has been used as a versioning tool so that all changes to the code base can be made explicit. A package management tool (renv; Ushey (2023)) is used to ensure that users have the correct version of the R packages. The training and test samples are openly available (cf. Wiegand, 2019), so it is easy to compare your own results with those of the tool presented here.[8]

2.2 State-of-the-art shallow learner via "Tidymodels"

We used the Tidymodels framework (Kuhn & Wickham, 2020) as our ML API. Tidymodels in turn builds on the idea of "Tidyverse" (Wickham et al., 2019), an idiosyncratic approach that tries to strike a balance between being powerful enough to produce high performance models and being easy to use. Some of the packages in the Tidyverse ecosystem are among the most downloaded and relied upon R packages.[9] The Tidyverse authors state

[8] https://heidata.uni-heidelberg.de/dataset.xhtml?persistentId=doi:10.11588/data/0B5VML

[9] https://www.r-pkg.org/, accessed 2023-05-25

that the "primary goal of the Tidyverse is to facilitate a conversation between a human and a computer about data" [Wickham et al. (2019); p1]. One advantage of any (good) approach that is widely accepted is that it provides a standard for how things should be done. Perhaps one of the main reasons for the success of the Tidyverse is that it addresses key problems faced by data practitioners and strikes a sensible balance between conflicting goals. In short, the authors describe their design principles as (a) human-centeredness, meaning that the software is designed to be read and written by humans, and only for computers to execute, similar to literate programming (Knuth, 1984), (b) consistency, so that all functions work in a similar way, (c) additivity, so that complex problems can be solved by breaking them down into small pieces, and (d) inclusivity, so that the community can participate in development. A more detailed introduction to Tidymodels is given by Silge & Kuhn (2022).

Tidymodels support a wide range of features that encompass recent requirements for ML software. The most important is the unified API for all ML algorithms and the complete coverage of all (typical) ML steps. For example, Tidymodels allows intelligent tuning of grid search methods such as simulated annealing. It provides outer and inner loops in cross-validation and includes pre-processing in cross-validation (e.g., tuning the number of components in a PCA). It provides many steps that makes data pre-processing simple such as dummyfying nominal variables, effect-coding them or over-/undersample their levels in the case of a class imbalance. Due to the rich ML ecosystem in R, from which many ML algorithms are made available in Tidymodels, users can choose from a wide array of state-of-the-art algorithms.

2.3 Project management via "Targets"

It has been said that perhaps the hardest problem in computer science is naming objects.[10] Then perhaps the next most difficult is dealing with complexity, at least from a helicopter perspective. To illustrate how complexity can creep in, consider the following example. Given a set of 10 possible actions, where you must choose the right 3 to solve a problem, you are left with 120 possibilities (as combinatorial mathematics requires). However, given a situation where you must choose 3 from a set of 20 again, you are faced with an enormous 1120 possible combinations (3 out of 30: 4060). In short, there's an explosion of complexity. Even a moderate increase in the number of possible actions can dramatically increase the number of possible combinations to choose from. The bad news is that there's no way out, thanks to the purity of mathematics. The good news is that the only thing to do is to reduce complexity to a level that is just low enough to be manageable. That's where project management comes in. There are many aspects to project management in software development; A well-known idea is "don't repeat yourself" (DRY), which could be translated as using macros (functions) to avoid repetition in code (Hunt & Thomas, 2000). A key feature of R is its functional programming orientation, which allows code to be cleanly composable. The project management tool used in this project is called "Targets",

[10] https://stackoverflow.com/questions/33497879/why-is-the-hardest-part-of-programming-is-naming-things

which is built around functional programming ideas (Landau, 2021). It is a GNU-Make like pipeline toolkit for R. Like Make, Targets ensures that the objects in a pipeline are updated when and only when necessary. That is, if an "upstream" object changes, and if that object is an input to a downstream object, then (and only then) will the downstream object be updated. Given the high cost of computation, it can be vital to know when an update is not needed. On the other hand, it is equally important not to miss an update when it is out of date. In short, as a project management toolkit, Targets (a) updates objects in a pipeline, and (b) keeps the pipeline tidy. An example is given below.

3. RESULTS

3.1 ML pipeline of the hate speech barometer

Figure 2 shows the pipeline of the hate speech barometer;[11] an interactive version of the diagram is available online.[12] In this graph, each node describes a target, and each edge shows dependencies between the targets with the arrows heading downstream. The appendix provides an overview in tabular form of the targets of the ML pipeline.

In the following, we describe the steps of the pipeline in some detail so that practitioners know what each step accomplishes. Instead of a "step" the term "target" could be used when seen from a functional programming view, focusing on the value (or output, result) of a function. For each step (or target) of the pipeline, we provide its name as used in the code along with a short description of what is achieved by the step. Where the step is complex enough to merit its own function, we provide the URL to the function.[13]

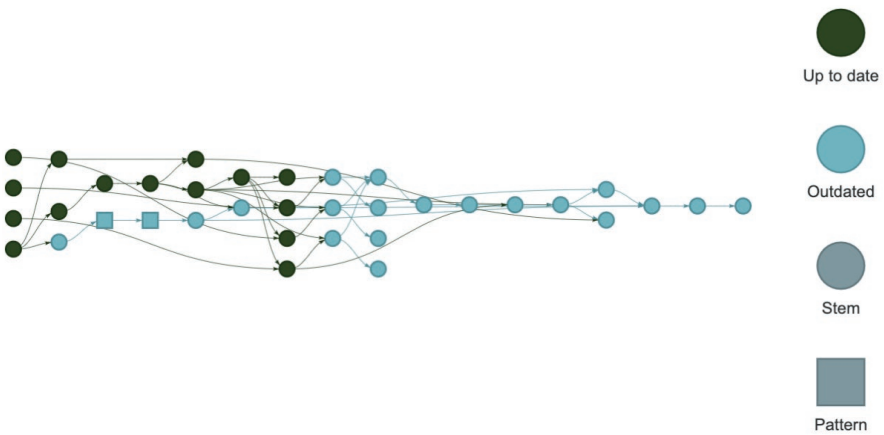

Figure 2. pipeline of the hate speech barometer.

[11] a "Pattern" refers to an object which is looped over; "Stems" are single-element Targets

[12] https://sebastiansauer.github.io/hate-speech-barometer/tar-visnetwork-pipeline3.html

[13] Please note that the URLs to the functions are still subject to change as the project is an early development phase.

3.2 Data pre-processing

Path: Defines the (relative) paths to the data.[14]

D_train and d_test: Imports train- and test-sample (based on the paths, that's why the object path is the input for this target).[15]

Recipe2, recipe2_prepped, d_train_baked, d_test_baked: Defines the pre-processing "recipe" of the data (prior to modelling) and applies it to the data sets.[16]

Recipe_plain, recipe_plain_prepped: As the data pre-processing was time consuming and had no tuning parameters it was taken out from the model workflow (and the cross validation) and conducted before the modelling, to save computation time. During the modelling workflow, a minimal pre-processing ("recipe") took place.

3.3 Modelling

Model_lasso, model_boost, model_rf: These three learning algorithms, i.e., the Lasso (L1 penalized regression), gradient boosting, random forests were computed in this analysis.[17]

Wf1, wf2, wf3: In Tidymodels, a workflow (wf) consists of pre-processing and the ML algorithm plus optional postprocessing. wf1 is the workflow consisting of the Lasso as ML algorithm; wf2: boosting, wf3: random forest. The pre-processing was identical in all three workflows.[18]

Wf1_fit etc.: The cross-validated, tuned workflow, i.e., the fitted model, where the model parameters have been estimated.[19]

Wf1_autoplot etc.: Diagrams depicting model performance (mean and sd) according to the selected performance measures (ROC-AUC in this case).

Wf_fits_l, wf_fits_roc, wf_fits_best: All models stored in a list-object (wf_fits_l) in order to render access to the model performance simple; wf_fits_roc contains all the performance measures (ROC-AUC), and wf_fits_best identifies the model exhibiting the best fit.

Wf3_finalized, final_fit, preds_test: The best performing workflow is chosen and initiated with the best performing tuning parameters (wf3_finalized), then, the whole train sample is fit with the best model, giving final_fit; on this base the test sample is predicted (preds_test).

[14] https://github.com/sebastiansauer/hate-speech-barometer/blob/main/R/set-path.R
[15] https://github.com/sebastiansauer/hate-speech-barometer/blob/main/R/read-test-data.R
[16] https://github.com/sebastiansauer/hate-speech-barometer/blob/main/R/def-recipes.R
[17] https://github.com/sebastiansauer/hate-speech-barometer/blob/main/R/def-models.R
[18] https://github.com/sebastiansauer/hate-speech-barometer/blob/main/R/tune-wf.R
[19] https://github.com/sebastiansauer/hate-speech-barometer/blob/main/R/tune-wf.R

3.3.1 Tweet classification

Tweets_path: A folder containing tweet data; in case of changes in the folder the target will be updated.

Tweets, tweets_df: The tweets are imported into R (tweets) using parallel processing due to large size; to save computational time, a random sample of tweets can be drawn (tweets_df).

Tweets_baked: The tweets are subjected to the same pre-processing as the train sample.

Preds, tweets_baked_preds: The tweets get classified (predicted) and the predictions are added as an extra column to the processed tweets (tweets_data_preds).

3.3.2 Pipeline outcomes

Preds_summarized: Proportion of hate speech per Twitter account, per year, s. Fig.[20]

Preds_summarized_plot: Plot for preds_summarized.[21]

3.4 Constants

Any ML pipelines depends on some constants, for organizational reasons (e.g., paths) or for model (hyper)parameters, to name two usual suspects. In this project, users can easily change their configuration in a (yaml) text file called config.yml. Advanced users can make use of the different Git branches of this project; whereas the main branch provides the standard pipelines, the "dev" branch offers more pipelines and experimental features.

4. CONCLUSIONS

4.1 Limitations

As this project is an early development phase, there are several threads suitable for further buildup. For example, the documentation of the project is still large lacking, which renders the access more difficult for less advanced users. In addition, deep learning methods are not yet implemented (although planned). Of course, users of any technical system strive for two opposing goals: feature richness and simplicity. The optimal balance between the two goals partly depends on the user's background and goals. That said, this project draws from an array of tools which implies that the user is accustomed to these tools (R, Git, Github, Targets, Tidymodels) and the underlying theory. Limited knowledge will place a barrier to easy access to the system. A further issue is that working with text data can place substantial burden on the computational resources. As to yet the present tool is not yet fully optimized to saving resources.

[20] https://github.com/sebastiansauer/hate-speech-barometer/blob/main/R/helper-funs.R
[21] https://github.com/sebastiansauer/hate-speech-barometer/blob/main/R/plots.R

4.2 Practical implications

There is a substantial number of case studies and tutorial on ML pipelines freely available on the web. However, there's still, to the best of our knowledge, no similar or template for a complex data analysis incorporating Tidymodels and Targets or similar tools within the R programming language.

In sum, it is our hope that the present research contributes to the detection of hate speech by providing a scaffold to the applied researchers so that he or she can focus on the phenomenon of hate speech rather on the technical intricacies of ML.

5. APPENDIX

The following table provides an overview of the targets of the analytic pipeline of the hate speech barometer.

Target name	Definition in R code
model_rf	def_model_rf()
path	set_path()
model_lasso	def_model_logistic()
model_boost	def_model_boost()
tweets_path_files	path$tweets %>% list.files(full.names = TRUE, pattern = "rds$")
d_test	read_train_test_data(path$data_test)
d_train	read_train_test_data(path$data_train)
tweets_path	tweets_path_files
recipe2	def_recipe2(d_train)
tweets	tweets_path %>% read_and_select() %>% drop_na()
recipe2_prepped	prep(recipe2)
tweets_df	tweets %>% sample_n(size = config$n_rows) %>% drop_na() %>% group_by(id)
d_train_baked	bake(recipe2_prepped, new_data = NULL)
d_test_baked	bake(recipe2_prepped, new_data = d_test)
tweets_baked	bake(recipe2_prepped, new_data = tweets_df)
recipe_plain	def_recipe_plain(d_train_baked)
wf1	fit_wf(model_lasso, recipe_plain)
wf2	fit_wf(model_boost, recipe_plain)
wf3	fit_wf(model_rf, recipe_plain)
recipe_plain_prepped	prep(recipe_plain)
wf1_fit	tune_my_anova(wf1, data = d_train_baked)
wf2_fit	tune_my_anova(wf2, data = d_train_baked, grid = 1)
wf3_fit	tune_my_anova(wf3, data = d_train_baked, grid = 1)
wf1_autoplot	autoplot(wf1_fit)
wf2_autoplot	autoplot(wf2_fit)
wf3_autoplot	autoplot(wf3_fit)
wf_fits_l	list(wf1 = wf1_fit, wf2 = wf2_fit, wf3 = wf3_fit)
wf_fits_roc	wf_fits_l %>% map(~collect_metrics(.x) %>% filter(.metric == "roc_auc")) %>% list_rbind(names_to = "id") %>% arrange(-mean)
wf_fits_best	wf_fits_roc %>% slice_head(n = 1)
wf3_finalized	wf3 %>% finalize_workflow(wf_fits_best)
final_fit	fit(wf3_finalized, d_train_baked)
preds_test	predict(final_fit, d_test_baked)
preds	predict(object = final_fit, new_data = tweets_baked)
tweets_baked_preds	enrich_preds(tweets_df, preds, tweets_baked)
preds_summarized	summarise_preds(tweets_baked_preds)
preds_summarized_plot	plot_preds_summarized(preds_summarized)

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TOWARDS AI-BASED INTERCULTURAL TRAININGS USING SOCIAL ROBOTS: DERIVATION OF DESIGN CRITERIA FOR EFFECTIVE INTERCULTURAL HUMAN- ROBOT INTERACTIONS

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ABSTRACT: The development of "ABCD" technology (Artificial intelligence, Blockchain, Cloud computing, and Big data) has promoted the design and development of new and innovative technologies, which fundamentally revolutionized the ways organizations manage themselves. However, digital transformations have also brought in new challenges. Against the backdrop of growing internationalization, cross-border collaborations, and increasing global trade, it is of utmost importance to explore how technology renovates the intercultural dialogues, negotiations, trainings, and the subsequent knowledge transfer processes. Researchers have suggested that technology will play a vital role in facilitating the need to work with people from all around the world. And from the perspective of intercultural exchanges, and cross-border/cross-cultural collaborations,it is necessary to know how to navigate the intercultural challenges effectively. The emergence of social robots like the Furhat allows to design rich human-robot interactions including verbal- and non-verbal communication elements, which is promising to deliver artificial intelligence (AI) -based intercultural training capabilities. This research project has two objectives: first, this research will bring in the AI factor in human landscape to explore the actions and interactions of AI and intercultural environment in transition; second, this study aims to provide orientations and recommendations for implementing interactions with social robots to enable AI-based intercultural trainings. Therefore, design criteria for implementing effective verbal and nonverbal interactions are outlined for achieving high standards of intercultural interactions to provide better understanding and interpretations of the contexts in which certain intercultural actions are practiced.

KEY WORDS: *Intercultural communication; Artificial intelligence; Social contexts; Furhat; Intercultural trainings, Social Robots, Human-Robot-Interaction.*

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1. INTRODUCTION

World economy has been witnessing tremendous cross border trade as a result of globalization and the subsequent internationalization by the firms, resulting in exponential growth among the multinational companies. Entering a new foreign market and diversifying the market portfolio bring employees from different cultural backgrounds into close contact through not only working relationships but also individual interactions (Ang et al., 2006, Bücker et al., 2014). The pressure on these companies to compete internationally and to properly deal with the consequences of globalization is increasing. Hence, it is becoming increasingly important to work together with people from different backgrounds successfully and effectively, especially in a multinational environment. Successful collaboration with people from other cultural backgrounds requires new cross-cultural competencies and new challenges for employees and managers alike (Bücker et al., 2014, Morley & Cerdin, 2010, Williams & Johnson, 2011). Thus, the ability to work with people from different cultural backgrounds and to understand different cultural contexts can be a great competitive advantage, as the multicultural composition of teams in such multinational companies is already a standard practice. The influence of culture on companies cannot be underestimated. In a Global Human Capital Trends survey conducted by Deloitte (2016), 82% of respondents believe that culture is a potential competitive advantage (Kaplan et al., 2016). Understanding the perspectives of other cultures can bring countless benefits to not only the organizations but also to the individuals. However, increased cross-cultural collaboration also increases the probability of cultural misunderstandings, tensions, and conflicts within the teams (Ang et al., 2007). According to Ikegami et al. (2017) cultural differences are often perceived as a burden. Each culture is defined by norms, beliefs and values which influence and complicate individual's thoughts and actions. In this case not knowing the fundamental rules of other cultures can cause misunderstandings among business partners with different cultural backgrounds (Triandis, 2006).

Therefore, employees in such multinational teams must acquire certain cross-cultural skills to be able to deal appropriately with colleagues from other countries. Appropriate communication regarding cultural standards can make the difference between success and failure, and the need for cross-cultural skills will be extremely important. In this context, the concept of culture, and subsequent understanding of cultural contexts can be extremely useful.

Furthermore, design and development of new and innovative technologies, which fundamentally revolutionized the ways organizations manage themselves, have exponentially increased the challenges international organizations face. Hence, as a result of growing internationalization, cross-border collaborations, and increasing global trade, it is of utmost importance to explore how technology renovates the intercultural dialogues, negotiations, trainings, and the subsequent knowledge transfer processes. In the same vein, emergence of social robots like the Furhat allows to design rich human-robot interactions including verbal- and non-verbal communication elements, which is promising to deliver artificial intelligence (AI) -based intercultural training capabilities.

By empowering Furhat to not only understand the culturally sensitive scenarios, and contextual exchanges, the potential to revolutionize the intercultural trainings is enormous. Furthermore, being able to offer an advanced and versatile technological tool can facilitate intercultural communication and develop deeper levels of understanding among the people from different cultural backgrounds.

2. RELEVANCE AND OBJECTIVE OF INTERCULTURAL TRAININGS

A genuinely good start in this intercultural world would be to understand another culture. More and more people engage in international trade but fail in their endeavors due to perceived insignificant cultural differences, which in reality can mean the difference between success and failure. Hence, mastering the art of interculturality is definitely an important skill to help achieve this. However, the ability to understand and comprehend the differences is far from a guarantee that a cultural exchange conducted by members with diverse cultural backgrounds will go smoothly. Therefore, it is imperative to be aware of culture-specific communication patterns, that can help facilitate this exchange. Similarly, it is much more about understanding the differences in how people from diverse cultures think, feel, and act. Ignoring this results in numerous misunderstandings due to language and cultural differences. Misunderstandings that are not clarified over the years can quickly become stereotypes. Intercultural trainings, with the focus on communication patterns, styles, social contexts must therefore be given special attention, as it is precisely this that is one of the most important key factors for creating and maintaining successful business outcomes in different countries.

In order to be able to master intercultural encounters successfully and reflectively on a private or professional level, one should, first of all, know what is actually meant by the term culture. At this point, however, it should be noted that the concept of culture is too elusive to do justice to it using a single universal definition. More than 60 years ago, Kroeber and Kluckhohn compiled 164 definitions of the concept of culture in their work (Kroeber & Kluckhohn, 1952). What is generally understood by culture and what constitutes culture is presented very differently in the literature.

Hall and Hall (1987) mentioned that culture is primarily a system for creating, sending, storing, and processing information. They equated culture as a shared program for behavior, with the definition of an extraordinary, huge, and complex computer that programs the actions and reactions of every human being. In order to make the so-called system work, these programs must be followed by everyone (Hall et al., 1987). Furthermore, Hofstede and colleagues (2010) defines culture as the "...collective programming of the mind that distinguishes members of one category of people from another" (Hofstede, et al., 2010, p. 6).

3. DESIGN CRITERIA FOR EFFECTIVE SOCIAL ROBOT INTERACTIONS

Autonomous robots are increasingly entering our daily life and it's expected that they support our daily life in sites like museums, schools, and hospitals (Pandey et al., 2018). social robots are autonomous robots which can demonstrate social behaviours. The social behavior includes for instance the verbal communication by understanding and producing speech in natural langue using text-to-speech and speech-to-text technologies. Furthermore, non-verbal communication elements like demonstrating facial gestures on the robot's face allow for instance the communication of emotions. Social robots can be seen as a specific form of conversational agents with a physical embodiment and by using voice as communication mode to allow human-like communication with the robot (Diederich et al., 2022).

Based on a literature review, Jung et al. (2021) concluded that the main objective of social robots is to provide meaningful social interactions with the users by being able to handle complex dialogues, to express and understand emotions and overall to possess personality and social competencies. This contrasts with traditional industry or service robots who are rather implemented to accomplish a single fixed task (Jung et al., 2021).

These social capabilities of social robots are promising to implement automated and interactive intercultural trainings for employees and students. This is especially because of their ability to handle complex interactions and specifically their ability to understand and express a broad variety of verbal and non-verbal communication.

From a user perspective several design criteria need to be considered so the interactions with the social robot in the context of intercultural trainings are accepted and therefore effectively used. In the case of social robots, the determinants of the acceptance are based on the one hand on classical acceptance criteria like perceived usefulness and on the other hand on the perceived humanness like the anthropomorphic design (Premathilake et al., 2022). In the following relevant constructs and theories are introduced which should be considered during the design of interactions with social robots to create effective intercultural trainings.

Anthropomorphisms and the Uncanny-Valley-Theory

The degree of anthropomorphism defines how human-like a social robot appears to be for the users. According to Pfeuffer et al. (2019), the features constituting a human-like design can be categorized into the following three categories:

- Visual features: e.g., Gestures, Mimics, Movements, or Appearance.
- Auditory features: e.g., Gender, Speech Synthesizer.
- Mental or Cognitive features: e.g., Personality, Emotionality, Cognitive Intelligence (for instance, to understand speech or images).

In general, prior research found indications that a high degree of anthropomorphism is related to a positive response towards the social robots. Nevertheless, the literature suggests that this relation is not simply positive linear but at a certain threshold a too human appearance can result in users having a perception of robots (Nissen and Jahn, 2021). This effect is described by the Uncanny-Valey-Theory, introduced by Mari (1970).

Acceptance Models

According to Davis' (1989) Technology Acceptance Model (TAM) the main determinants of users' acceptance of a new technology are perceived usefulness and perceived ease of use. The Perceived usefulness is defined by Davis (1989, p. 320) as "the degree to which a person believes that using a particular system would enhance his or her job performance." Perceived ease of use is defined as "the degree to which a person believes that using a particular system would be free of effort" (Davis 1989, p. 320). This model was extended by Davis et al. (1992) by the construct perceived enjoyment, which in subsequent studies could be verified to be one relevant determinant for the acceptance of a system and is frequently used in social robot research (Jung 2019). Based on this model the Almere Model of Acceptance was developed in the context of social robots and their interaction with elder users (Heerink et al., 2010).

4. THE SOCIAL ROBOT FURHAT AS EXAMPLE FRAMEWORK FOR IMPLEMENTING SOCIAL ROBOT INTERACTIONS

The social robot Furhat from the company Furhat Robotics is promising to design rich verbal and non-verbal interactions based on the integrated AI capabilities. The Furhat is a head containing a projected facial animation and includes a voice-based multiparty conversational system (Moubayed, 2012; Moubayed, 2013). In the following section, possible design elements for designing interactions for training intercultural communications are outlined based on the categorization of Pfeuffer et al. (2019) introduced in the last section.

Visual features

The Furhat framework makes it possible to select one of several predefined face designs or to integrate own facial designs. As illustrated in Figure 1, multiple predefined facial designs representing various age groups, genders, ethnical backgrounds, as well as cartoon and robotic characters are available.

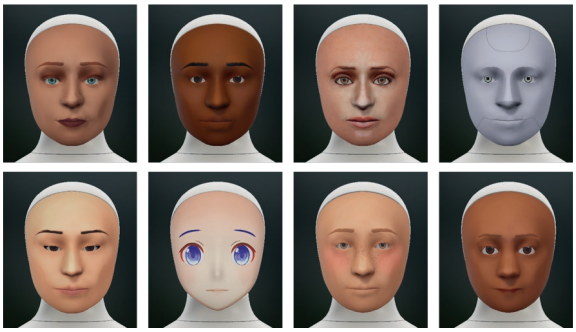

Figure 1. Example of predefined facial designs in the Furhat framework. Screenshots based on the virtual Furhat.

During the interaction with the users, the artificial faces can express multiple gestures to convey emotions as illustrated in Figure 2. To make the social robot appearance closer to a real human person, it is also able to automatically smile back if a user's smiles, and to continuously run micro-expressions like blinking, small facial movements in the area of mouth and eyes as well as permanent little movements of the eyes gaze.[1]

Auditory features

The Furhat supports more than 40 languages with various voices in all genders. For the speech synthesis Furhat supports onboard voiced running directly on the social robot as well as cloud-based providers like Amazon Polly. Beside speech synthesis also pre-recorded audio files can be used. The lips of the artificial face automatically sync to the output audio. The speech can also include pre-recorded audio files.[2,3]

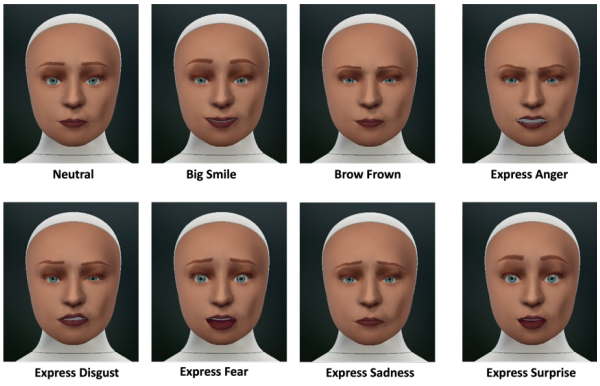

Figure 2. Example of predefined gestures in the Furhat framework. Screenshots based on the virtual Furhat.

[1] Source: https://docs.furhat.io/gestures/ (accessed on June 3rd, 2023)
[2] Source: https://docs.furhat.io/speech/ (accessed on June 3rd, 2023)
[3] Source: https://furhatrobotics.com/docs/Furhat-Robotics-Technical-Product-Overview.pdf (accessed on June 3rd, 2023)

Mental or Cognitive features

To create rich interactions, the Furhat applies AI for the visual perception of users. This includes face and facial gesture recognition.[4] For designing the conversation flows, a virtual Furhat is offered which makes it possible to develop and test the conversations on a personal computer without the need of having a physical Furhat available. Simple conversations can be implemented with a graphical programming interface called blocky.[5] Advanced workflows can be created directly in the Furhat skill framework by using the Kotlin programming language.[6] Alternatively, external conversational systems like the Rasa conversational framework can be connected via an API.[7]

5. SUMMARY AND FUTURE RESEARCH

The overarching objective of this article is to introduce and motivate research in the intersection of AI and especially social robots and the field of intercultural communication and particularly intercultural trainings. Furthermore, this research intents to provide orientations and recommendations for implementing interactions with social robots to enable AI-based intercultural trainings. This is done by compiling an overview of relevant concepts in the field of culture, social robots, and relevant design criteria regarding user acceptance. A detailed example of design aspects of social robot interactions is given based on the social robot Furhat. This overview can be a basis for future research on the design and effectiveness of intercultural trainings via social robot interactions.

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[5] Source: https://docs.furhat.io/blockly/ (accessed on June 3rd, 2023)

[6] Source: https://docs.furhat.io/tutorials/your_first_skill/ (accessed on June 3rd, 2023)

[7] Source: https://furhatrobotics.com/docs/building-applications-with-the-furhat-robot.pdf & https://rasa.com/ (accessed on June 3rd, 2023)

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A BIBLIOMETRIC ANALYSIS ON RECIPROCAL HUMAN-MACHINE INTERACTION

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ABSTRACT: Research into artificial intelligence is not a very young field; its precursors can be traced back as far as the 16th century. Today's technical development, however, is virtually leaping forward, with new intelligent chat systems and social robots playing no small part in this. This is revolutionizing a wide range of scientific and social fields. The very large publication numbers in this field illustrate this as well. In order to keep track of the discourse in the field, the representatives of the field, the publications as well as the topics and their future development, it is indispensable for academics and scientists to prepare them in a bibliometric analysis. Only in this way it is possible to uncover thematic gaps as well as further points of contact and to drive research forward in a targeted and stringent manner. It is precisely this sorting and processing of the research discourse, the topics, and the authors, which is necessary for further research, that is carried out in this paper. For this purpose, using bibliometric analysis tools, an overview of the past, present, and future of the research field is created, and the general relevant topics are uncovered. The analysis includes as performance analysis a) the total number of publications and b) the total number of citations, and for science mapping c) a co-citation analysis (past), d) a bibliographic coupling (present) and e) a co-word analysis (future). The data needed for the analysis are identified and extracted from the SCOPUS or Web of Science (ISI) databases.

KEY WORDS: *Human-robot interaction; human-machine interaction; bibliometric analysis; social robots.*

1. INTRODUCTION

The field of artificial intelligence is growing steadily and spreading into all areas of life - from technical support at work to service offerings and even into private life for entertainment and information gathering. With natural language processing (NLP), machine learning and conversational agents, for example in the form of new intelligent chat systems such as Chat-GPT and social robots that use these systems to communicate verbally with humans, a revolution is taking place in a wide variety of areas.

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Androids, which were supposed to imitate human abilities such as writing, were already developed in Europe from the 16th century onwards. At this early stage, however, robots were used purely to mimic human actions and the 'mind' of the machines was not yet considered, as it is now in artificial intelligence research. The greatest challenge in AI research is "replicating the flexibility and adaptability of human intelligence" (Dautenhahn, 2007, p. 679). Research into AI, with a focus on human intelligence, can be dated back to the 1950s. All of today's so-called artificial intelligences are weak artificial intelligence or narrow AI. This can, for example, offer correction suggestions in search processes, recognize language, or navigate – in other words, apply algorithms to solve certain processes. The goal of research is to develop a strong artificial intelligence that can fully map human thought processes and has universal, all-encompassing problem-solving capabilities. This means that it can make decisions under uncertainty, is creative, has its own consciousness, and can also feel empathy – that is, it can imitate the processes in a human brain (Harwardt & Köhler, 2023; Buxmann & Schmidt, 2021; Funk, 2022).

The imitation of human intelligence (weak AI) via certain artificial cognitive abilities can be chalked up as one of the successes in the course of research, yet the road toward real, strong AI is not yet over (Dautenhahn, 2007). In these efforts, a leap forward can be observed in the latest developments. With new and powerful versions of text generators and social robots mimicking humanity, large and important fields are opening up in research on human-machine interactions (Young et al., 2010). One such social robot, which is at the forefront of technical development, is 'Furhat'. The subject areas related to AI are extremely diverse. However, preliminary research has identified a few areas in which there is still potential for further development. In the area of trust and acceptance, for example, there still seems to be such potential (Korn et al., 2021). There is a need for research that investigates how the trust of humans in robots can be developed and how trust affects the interaction between humans and robots. There is existing research on this, yet this area has further points of connection (Carli & Najjar, 2021).

There are also unanswered questions in the area of ethics, especially in the context of medicine and care. One important question is how to consider ethical issues in the context of human-robot interaction (HRI) research, particularly in relation to the use of robots in sensitive areas such as healthcare and nursing (Wilcock & Jokinen, 2022; Fosch-Villaronga et al., 2020; Ostrowski et al., 2022). Long-term effects of human-robot interactions in terms of human development and social life are also an area of current research (de Graaf et al., 2016; de Graaf, 2016). Interaction design, in particular, also plays a central role in human-robot interaction research. How should the interaction interface of social robots be most appropriately designed so that the interaction can proceed in the best possible way? Likewise, one difficulty is successfully inserting social robots into group interactions, as well as how they should or can be best used and analyzed in group interactions as Oliveira et al. (2021) states. Not to be neglected are also the psychological implications. There is a need for research that examines how interaction with robots affects human psychology and how this can be addressed in human-robot interaction research (Kanda et al., 2001).

In addition to these topic areas, continuing research on 'Uncanny Valley' theory through new technologies such as social robots, explicitly Furhat, would also be a relevant field as these technologies offer new, better ways to mimic human traits (Mathur et al., 2019; Mori et al., 2012; Chen et al., 2010). This field can also be combined with the topic area of 'gaze' to gain insightful insights into, among other things, human-robot interaction, trust, and acceptance (Perugia et al., 2021). Attention to these topics has currently only emerged through a review of the literature. The targeted bibliometric analysis will provide information on the extent to which these gaps have already been further filled or other gaps have emerged.

2. AIM AND METHOD

Accordingly, the number of publications in this very topical research field is increasing rapidly, making it difficult to grasp the field in its entirety. Similarly, fragmentation of the research field is occurring due to the greatly accelerated generation of knowledge in the field of human-robot interaction, making it difficult to stay at the forefront of research or to evaluate the collective findings in specific areas (Stock-Homburg, 2022). Yet building on and relating existing knowledge is the building block of all academic research activities and doing so as accurately as possible should be the priority of all academics (Snyder, 2019).

In order to get an overview of the topics, authors, research institutions and publications, and even better, to get an overview of the currently relevant topics and research discourses, as well as to identify potentially important research content and discussions in the future, it is advisable and of great importance to conduct a bibliometric analysis of the topic area. Likewise, such an analysis will reveal collaboration patterns and journal performance and, in general, the intellectual structure of the research field (Donthu et al., 2021). In the subsequent step, based on the results, the analysis allows to identify the content gaps in the research and to fill them. The general goal of this paper is to provide a structured overview of the field of human-machine interaction for current and future researchers. Thus, the current state of research is to be disclosed and the collective findings or topics are to be elaborated and research gaps are to be identified in order to be able to specifically advance research at the appropriate point (Snyder, 2019). The bibliometric analysis presented in this paper specifically aims to explore the knowledge area of reciprocal human-machine interaction and to provide a comprehensive picture of what is happening in science about it. To this end, using a combination of appropriate analysis and representation tools (an overview of which can be found in Cobo et al., 2011; Donthu et al., 2021; Mukherjee et al., 2022), an overview of the past, present, and future of the research field is provided, as well as uncovering the general relevant topics, because surveying the research field and its "trends and issues in terms of topics and methods" (Lee et al., 2004, p. 225) is "pivotal in the advancement of research" (Lee et al., 2004, p. 225). In particular, looking into the past and present of the research field also holds great practical value in generating

knowledge about and insights into that research field as well as its future development (Chen et al., 2021). For this purpose, it is elementary to review and sort the relevant literature.

For an overview of the research field, a performance analysis is first performed, in which the total number of publications and the total number of citations are used for analysis. This covers the two central aspects 'publication-related metrics' and 'citation-related metrics' of the performance analysis. This is followed by a co-citation analysis for the past aspect, a bibliometric coupling for the present, and finally a co-word analysis to generate an outlook for future research (Donthu et al., 2021).

In order to reveal the research topics as a second aspect, the author keywords are taken into account in the co-word analysis in addition to the above aspects, which are also useful for revealing topics.

This leads to the research questions:

RQ1: What is the current state of the field of human-robot interaction? This is achieved through the total numbers of publications, the total number of citations as well as identifying the main topics.

RQ2: What are the main authors regarding human-robot interaction and how are they connected? How is the collaboration respective the network of these authors? This is achieved through the total number of citations of the existing papers, the co-citation analysis and bibliometric coupling.

RQ3: What are the past and present issues regarding the field of human-robot interaction and where will they eventually go? This is achieved both through the keyword and the co-word analysis as well as the bibliometric coupling.

Especially RQ2 and RQ3 aim to uncover the intellectual structure in the research field of human-robot interaction.

Both for the overview of the research field and for the aspect of uncovering the research topics, a network analysis is performed within the framework of "enrichment techniques" (Donthu et al., 2021, p. 288). Here, a clustering and an explicit network analysis "over the generated maps to show different measures of the whole network or measures of the relationship or overlapping [...] of the different detected clusters" (Cobo et al., 2011, p. 1382) shall be completed.

As a further step, the data field must be explored for the analysis. Literature databases such as Web of Science (ISI), SCOPUS, Google Scholar, or MEDLINE are useful for this purpose. For reasons of accessibility and comprehensiveness of the databases, either Web of Science (ISI) or SCOPUS will be specifically relied upon for the analysis data, but probably Web of Science (ISI).

Subsequently, the 'raw mass' of data must be extracted from the databases or the database via the appropriate choice of search terms, which on the one hand must be broad enough, but on the other hand also focused enough. This data has to be merged and cleaned before use to weed out aspects of duplication, misspellings, or simply irrelevant data etc. To what extent this step is economical to perform for our research is questionable, as the data base is very large (between 4,000 and 6,000 papers). Possibly the data cleaning can be omitted, since the 'power of large numbers' makes the number of erroneous data negligible.

Now the step of bibliometric analysis using the selected analysis aspects and analysis tools takes place. This step is followed by the visualization and presentation of the results as well as their discussion. Suitable tools for analysis and visualization are, for example, Bibliometrix R and VOS-Viewer. An overview of the different tools, as well as their advantages and disadvantages, is provided by Cobo et al. (2011) and Donthu et al. (2021), among others.

Since our goal is to analyze the topic area of human-machine interaction around social robots the search query for Web of Science was developed accordingly. In this regard, there are now two datasets that are promising. The first one includes 5503 works and is related to human-machine interaction and social robots. For the second dataset, the Citations Topics Micro 'human-robot-interaction' was added. This dataset includes 4159 pieces of writing. For both datasets, the publication time span of 2013 to 2023 was chosen. The entry in 2013 is justified by a rapid increase in publication numbers in that year. From these two datasets, the bibliometric analysis is completed.

At this early stage of the research, We cannot yet share very detailed analysis results, but at least briefly present the dataset numerically and raise one or two questions and expectations. Since the research is still in its starting phase, the results are also not fully complete yet and will be revised later on.

3. RESULTS

Since the research is still at a very early stage, presenting 'correct' results is still almost impossible at this point. The following presentations are rather an overview of the relevant data, which serve as a basis for analysis and numerical results. An interpretation has yet to be made with the in-depth analysis. Likewise, nothing can be reported at this point about the thematic orientations of the relevant authors, papers, and clusters. Nevertheless, some questions are raised, and assumptions are made, which will be clarified or verified in the course of further research. The first question that came up when the data sets were adjusted is why in the year 2013 the publication numbers suddenly increased seriously.

The step of choosing the data basis neither too narrow nor too broad already revealed an interesting aspect. When comparing the two data sets that would be considered for the analysis, it can be seen that the rough content remains the same, only the focus shifts. The

first data set provides a rather broader overview (more than 5,000 papers) of the various specific subject areas. The second, on the other hand, provides a more detailed look at the areas dealing with human-robot interaction (more than 4,000 papers).

The analysis aspects for both datasets will be compared in the following as a first step. The later paper will most likely focus on the smaller, more detailed dataset, based on both datasets.

The most relevant source is the International Journal of Social Robotics followed by Sensors and Frontiers in Robotics and AI. The IJoSR has 136 documents, Sensors has 85 and FiSR has 62. As it is shown, the gap between them is quite high. There are some other journals that have between nearly 50 and 60 documents and build a group in the middle. All other sources have quite a few documents less. Even though it is journals with the most published documents, it is the ACM/IEEE International Conference on human-robot interaction that is the most locally cited source. This is an indicator, that the field of human-robot interaction conferences and proceedings are a valuable tool of sharing research results. On the second place is the journal International Journal of Social Robotics, which also has the most local impact.

The second database is quite similar to the first one. Again, the International Journal of Social Robotics (281 documents) is in first place for the most relevant sources as well as for the highest local impact, followed by various years of the ACM/IEEE International Conference. Regarding the most locally cited rank the places switch. There is the ACM/IEEE with a good distance on the first place followed by the International Journal of Social Robotics. This strengthens the impression, that conference proceedings are a relevant part of sharing information and publishing research results within the field of human-robot interaction.

Figure 1. WordCloud database one by Bibliometrix R.

As the WordCloud (Figure 1) shows for the first data set, the thematic focus here according to the 'Keywords Plus' of Web of Science is on more technical-developmental areas. First and foremost is design, but model and system are also major topic areas. The leap to people seems to be made via recognition, which is closely connected with the design. If we only look at the author keywords, human-machine interaction is clearly in the foreground, followed by 'social robot' and in third place human-robot interaction. This could indicate that the field of human-machine interaction weights the technical aspects more strongly than the field of human-robot interaction, especially when compared to the WordCloud results of the second dataset. Here, for the 'Keywords Plus' behavior and children are in the center and design only in third place followed by anthropomorphism.

Analysis by major authors has identified, by narrow margins, Y. LI, Y. Wang and S.S. Ge. The basis of analysis was the number of publications in the analysis period (2013-2023) on the filtered topic. The local impact, measured by the H-index, on the other hand, shows a different picture. Here, S. S. Ge is clearly in first place followed by Y. Li, and C. Breazeal. Y. Wang, on the other hand, is in 10th place. The most affiliated university is the National University of Singapore which has more than 100 publications more (in total 241 publications) then the second place the Tsinghua University in Beijing, China.

In contrast to these results, the second data set shows that the most affiliated university is Osaka University, followed by the University of Lisbon, which is only in sixth place in the first data set. Basically, the affiliation is strong in the European region instead of the Asian region.

Accordingly, the most frequently cited countries for the first data set are China by a wide margin, followed by the USA and Germany. Singapore is on the sixth place, even if the university in Singapore is the most affiliated one.

For the second dataset, it can be seen that the USA is in first place by a significant margin – it also follows that the USA can boast the most scientific productivity – followed by the UK and Germany. Again, the most affiliated university is not located in the country that is cited the most. Nevertheless, Japan is in fourth place.

The most global cited documents are a paper from 2017 by M. Liao in the journal Advanced Functional Materials and a paper by R. Jenke from the Jear 2014 published through the IEEE Transactions on Affective Computing. The third most cited paper, with a difference of about 140 citations, is also a proceeding from the IEEE International Conference on Industrial Informatics. Locally the most cited documents are a paper by M.M.A. de Graaf from 2013 (Robotics and Autonomous Systems) at first place and one from 2015 on third place (Computers in Human Behavior). The second most locally cited contribution is by C. Breazeal from 2016 in the Springer Handbook of Robotics.

For the second database the three most globally cited documents are all from 2013. The first is by I. Leite from the International Journal of Social Robotics, the second is a proceeding in the 8th ACM/IEEE International Conference on human-robot interaction by A.D. Dragan and the third is by H. Robinson in the Journal of the American Medical Directors Association. I. Leite's paper is also the most locally cited one.

'Authors' was selected as the unit of analysis for clustering. The parameters were 'References', 'Global Citation Score' and 'Keyword Plus'. This resulted in a picture that shows a quite clear separation of the Asian area, mainly the Chinese areas. There are some upstream links of Chinese authors, which increasingly refer to non-Chinese authors, but still the separation is clearly visible.

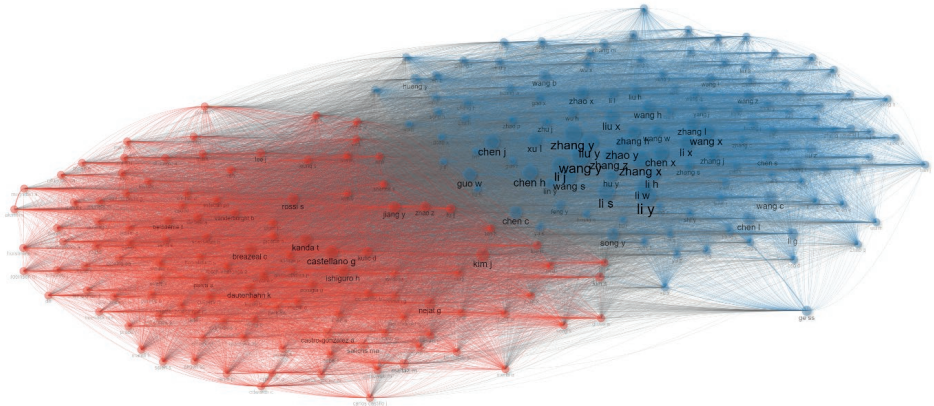

Figure 2. Clustering by authors.

One aspect of the bibliometric analysis would be to reveal the topical structure behind those connections. The authors referencing each other must have some common points regarding their work and papers.

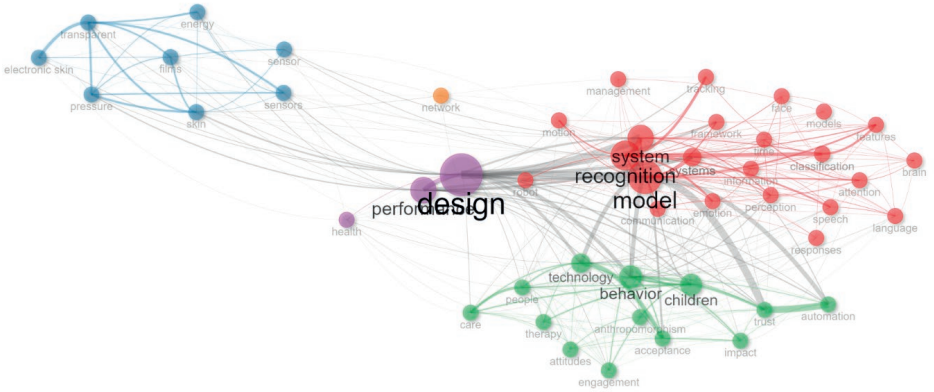

Figure 3. Co-occurrence network (human-machine interaction).

The co-occurrence network (Figure 3) in relation to the keywords plus clarifies the distinction into four plus one areas with different thematic characteristics.

- Probably the largest area (red) deals mainly with topics like ‘model’, ‘recognition’ or ‘system’.
- The second largest area (green) deals with ‘behavior’, ‘children’ and ‘technology’.
- The next largest area (blue) does not have any prominent topics but generally deals with various technical aspects such as ‘sensors’, ‘pressure’ and ‘energy’.
- In fourth place is an area (violet) that is very small but very much ‘design’ themed. ‘Performance’ follows on second place.
- The last area, the ‘plus one’ area (orange), includes only one topic: ‘network’.

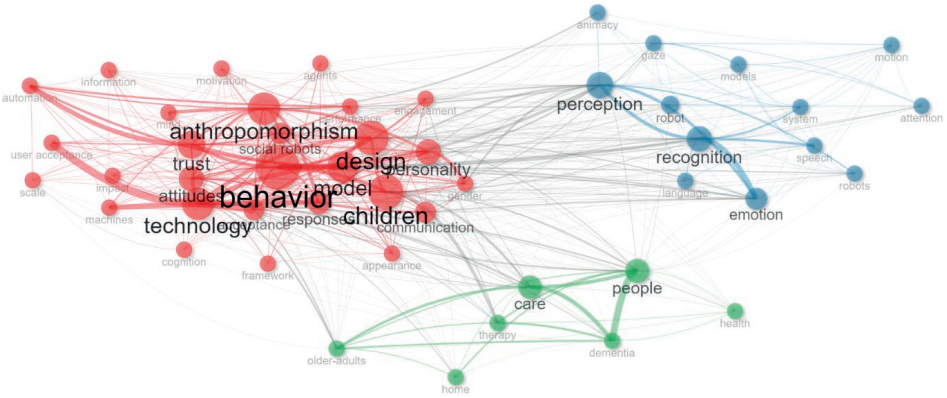

Figure 4. Co-occurrence network (human-robot interaction).

As shown for the second data set, about the human-robot interaction, there are only three areas. The first one is mainly about behavior, children, anthropomorphism, and technology. The second one is mainly about ‘recognition’ and ‘perception’ and the third one mainly about ‘people’ and ‘care’.

The thematic map of the first data set is similar to the co-occurrence network of the second data set. Three thematic areas can be identified here. One is about ‘design’, ‘performance’, and ‘model’, the second about ‘children’, ‘behavior’, and ‘technology’, and the third is more or less equally about technical aspects such as ‘sensor’, ‘pressure’, etc...

A more in-depth analysis could reveal how the topics and themes identified using Keywords Plus are interrelated, but also how the topics intertwine within their domain.

For the thematic map, the second data set shows at first glance a somewhat stronger interweaving of the topics, especially around the topics ‘behavior’, ‘design’, ‘children’ and ‘technology’.

The intellectual structure is formed by the co-citation network. The most represented papers are by B. Reeves (1996), T. Fong (2003), C. Bartneck (2009), I. Leite (2013) in the same cluster, and T. Kanda (2004) and T. Belpaeme (2018) in the second largest cluster. It is surprising that the paper by T. Belpaeme (2018) is the second most represented, although it is still very young compared to the other papers. Obviously, key findings or a large interface with others were hit here.

Compared to the co-citation network of the second dataset, in which a total of four clusters can be identified, T. Fong (2003) and C. Bartneck (2009) each come from one of the two largest clusters and are also most strongly represented in each. In this respect, the two data sets are very similar. It is also evident that these two clusters are clearly the most strongly networked with each other. The thematic orientation of the cluster around T. Fong mainly comprises 'children', 'people', 'care', 'engagement', and 'therapy' and that around C. Bartneck mainly 'behavior', 'design', 'technology', 'responses', 'personality', and 'Social Robots'.

The two largest areas of collaboration appear to be in China and Singapore.

The social structure of the second data set shows that there is definitely networking within the same country, but networking at the international level is very weak.

4. CONCLUSIONS

Since the bibliometric analysis has only just started, drawing any tenable conclusions is nearly impossible. Even though some questions and assumptions or impressions have already occurred. What met the eye in this early state of the research was on one hand the sudden increase of numbers of publications regarding human-robot interaction in 2013 but also a sudden massive drop of the scientific productivity, average citations per year and number of publications after 2021. The presumption is obvious, that in both years something must have happened that shifted the scientific interest. Maybe the COVID pandemic had an influence on the number of publications and scientific productivity in this field of research. In addition, papers from 2013 are still in the top three most cited papers. That, too, speaks for highly relevant research results in that year.

It was also noticeable that H. Ishiguro has by far the largest number of publications but is cited significantly less than other authors. There may be a connection with his publication activity, which tends to be most frequent in early stages of the subject as well as again more recently. In between, there is a publication gap.

Since 2018 the Osaka University made a leap forward in activity and before the year 2019 it is the most affiliated university. And since 2020 it is by far the most affiliated one. There must be a reason behind that. Maybe it is connected to the research topics there or the authors respectively the researchers that are involved with the Osaka University.

Even though the most affiliated university is a Japanese one and the most productive author is also a Japanese author the most corresponding author's countries is the USA and after a good distance on second place is Japan. Third place goes to Germany. And as the productivity over time shows, it was for most of the time that case. Only between 2013 and 2014 Japan was ahead of the USA but the USA has a steep increase in productivity. What happened in the USA in 2014 and especially in 2015 that led to that drastic increase? Maybe it is connected to scientific companies like OpenAI is one nowadays, that increased the interest and focus on the topic of human-robot interaction.

Also is Japan only on the 4th place regarding the most cited countries. Might there be a difference in overall research topics, since we know the Osaka University and H. Ishiguro are quite relevant, but the rank of the most cited countries is not as high as one may expect.

Another point that stood out is the importance of proceedings regarding the topic of human-robot interaction and the fact that when they get neglected in the database some branches are barely represented anymore in the bibliometric analysis. A possible conclusion here would be, that those branches mainly focus on publishing conference proceedings instead of regular papers. Another hint to the importance of proceedings could be the number of citations they receive and the fast increase of those numbers, especially in the year after their appearance.

Regarding the topics it seems that in the field of 'trust', 'recognition', 'perception', and 'care' might be a research gap existing, since the created word cloud created by Bibliometrix R lists those words respectively topics as the last ones – therefore the least noticed ones.

As it also seems, the topics are at least in some branches quite highly connected to each other, at least for the second database. This shows the clustering and thematic map and especially for two authors (C. Bartneck and T. Fong) the co-citation network. The social structure on the other hand paints a different picture. Here the authors are collaborating very much on a local level rather than an international one. Might that be because of the topical orientation within each country and the possible differences between them?

5. RESEARCH LIMITATIONS AND VALUE

The keywords from Web of Science for the data sets are only 'acceptable'. However, one observation here was that for paper the keywords turned out 'good', but for 'proceedings' they turned out 'poor'. This means that the keyword-based analyses are more useful for paper than for proceedings. Nevertheless, these should not be neglected as they seem to constitute an important part of communication and publications. There seem to be branches that treat the topic human-robot interaction but are mainly writing proceedings

instead of papers. If I would neglect those the overall picture of the research landscape (authors, papers, institutions, etc.) would be distorted. Nevertheless, this must be considered for that bibliometric analysis.

For the datasets, no data cleaning took place due to the sheer mass of data. The power of the large numbers, however, should be sufficient to dispense with this step, since the overall result is not relevantly influenced by the comparatively small amount of possibly erroneous data and thus no significant bias arises.

In the later on full bibliometric analysis the comparison between the two sets of data might not be the focus of the work. Rather will the focus lie on the smaller, narrower database which goes more specific in the direction of human-robot interaction, which is of more relevance for this research.

The value of this research is to give a detailed overview regarding human-robot interaction, especially regarding the given research questions, in form of a paper. This should enable and promote further research. Only through the identification of research gaps will it be possible to focus existing research capacities on the right goals in a targeted and beneficial manner and to deliver new important findings.

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AUTHOR CONTRIBUTIONS

Matthias Erdmann: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Resources; Visualization; Roles/Writing - original draft; Writing - review & editing. Prof. Dr. Maria Rosario Perelló Marin: Supervision, Reviewing, Validation. Prof. Dr. Maria Esperanza Suárez Ruz: Supervision, Reviewing, Validation. Prof. Dr. habil. Sebastian Sauer: Supervision, Reviewing.

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GENERATIVE AGENTS TO SUPPORT STUDENTS LEARNING PROGRESS

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ABSTRACT: Ongoing assessments in a course are crucial for tracking student performance and progress. However, generating and evaluating tests for each lesson and student can be time-consuming. Existing models for generating and evaluating question-answer pairs have had limited success. In recent years, large language models (LLMs) have become available as a service, offering more intelligent answering and evaluation capabilities. This research aims to leverage LLMs for generating questions, model answers, and evaluations while providing valuable feedback to students and decentralizing the dependency on faculty. Our approach is based on the development and interaction of advanced AI-powered generative agents, built on large language models like ChatGPT, GPT-4, and Vicuna, and designed to emulate human activities such as information abstraction, context refinement, and query rating. These agents interact autonomously in a network, employing techniques like Zero-Shot and Few-Shot Prompting to generate responses and adapt to various roles and contexts. The setup includes three key agents for question generation, refinement, and quality assurance, which leverage text vectorization, document selection and filtering, and cutting-edge language models to generate, refine, and evaluate questions and answers based on specific learning objectives. In conclusion, this paper demonstrates the versatility of LLMs for various learning tasks, including question generation, model answer generation, and evaluation, all while providing personalized feedback to students. By identifying and addressing knowledge gaps, LLMs can support continuous assessment and help students improve their understanding before semester exams.

KEY WORDS: *LLM; Question Generation; Generative Agents; Personalized Assessments.*

1. INTRODUCTION

In the quest for educational excellence, a crucial aspect is ensuring students consistently meet the learning objectives (Bulut & Wongvorachan, 2022). To achieve this, it is vital to measure and track the students' state of knowledge throughout the course continuously.

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However, this proves to be a significant challenge for educators, especially when dealing with hundreds of students and different courses. The generation and correction of questions, though necessary for personalized feedback and assured learning progress, is a time-consuming process. To overcome these problems, we propose an automatic assessment generation and feedback system based on generative ai agents, which generates learning goal-based assessments and performs correction after each lesson, with a primary focus on enhancing learning progress.

One innovative concept this paper will explore is automatic question generation from documents, slides, transcriptions, or recommended reading materials. This raises the critical question of how to select essential paragraphs for question generation. Further, to ensure the quality of learning, we need to generate thought-provoking questions that go beyond simple multiple-choice queries and stimulate deeper thinking in students. This, however, poses the problem of assessing the quality of such questions. In addition, the question which is generated should not only focus on one paragraph or section rather should also be more focused on questions that force the students to use their knowledge to answer it.

In addition to question generation, automatic correction and guidance form a significant part of our proposed solution. While multiple-choice questions are relatively easy to grade automatically, open-ended answers present a more complex problem for automated correction. Beyond just identifying the right or wrong responses, the system should also be capable of providing constructive feedback and guiding the students towards improved responses, and showing ways how questions could be answered in a more familiar way (Kulshreshtha et al., 2022).

By addressing these issues, this paper aims to lay the foundation for a dynamic and effective automated learning tool, capable of handling large-scale education with personalization and efficiency.

The contribution of this paper is to show how generative agents which autonomously identify the important section of the given supporting material, extract questions, refine and evaluate the question toward the learning goal, and support the correction process could be set up by using prompt engineering and different large language models.

Delving further into the concept of automatic question generation from documents and recommended books, the first issue that arises is the selection of important paragraphs. Generating high-quality questions from these important paragraphs is another challenge. The idea is not to simply produce factual recall questions but to design queries that foster critical thinking and deep comprehension. However, the notion of quality in question generation raises another concern. Quality can be measured based on relevance, difficulty level, clarity, and the type of cognitive skills they target, such as recall, analysis, or evaluation (Gnanasekaran et al., 2021; Sen Gupta et al., 2019; Xie et al., 2020). Developing an assessment model incorporating these factors would be necessary for a successful automatic question-generation system.

Automatic correction and feedback for non-multiple-choice questions is another crucial component of our proposed system. As open-ended responses cannot be evaluated against a set of predefined answers, novel solutions are needed.

Providing automated recommendations for better answers is equally important. Here, the system would not only indicate the errors but also guide the student to the correct understanding. This could involve the generation of partial answers or hints, suggesting relevant resources, or pinpointing the parts of the original text that the student should revisit, like it is proposed also in Kulshreshtha et al. (Kulshreshtha et al., 2022).

All these aspects aim to foster a more interactive, engaging, and effective learning experience, ensuring that the students aren't simply memorizing information, but truly understanding and assimilating it.

2. RELATED WORK

The role of assessments in education has been significantly automated using technology, with numerous studies employing natural language processing (NLP) and machine learning (ML) for test creation. Malinova and Rahneva (Malinova & Rahneva, 2017) and Botelho et al. (Botelho et al., 2023) proposed methods for automated question generation in English and mathematics respectively. Emerson et al. (Emerson et al., 2022) introduced the use of fine-grained content for student performance prediction during tests. Transformer-based models for reading comprehension test generation were studied by Bulut and Yildirim-Erbasli (Bulut & Yildirim-Erbasli, 2022) and Runge et al. (Runge et al., 2022). Zou et. al. (Zou et al., 2022) proposed a method to generate true/false questions for reading comprehension tests based on unsupervised learning methods by leveraging different NLP techniques and a generative framework by a novel masking-and-infilling strategy. Yet, most automatically generated questions, especially those based on manually generated rules, lack linguistic diversity or unusable content. Therefore a shift towards generated questions based on neural networks occurred (Zou et al., 2022).

The importance of inclusive assessments was highlighted by Johnson and Monroe (Johnson & Monroe, 2004), while Mislevy et al. (Mislevy et al., 2002) discussed task-based language assessment models. Freeman et al. (Freeman et al., 2015) emphasized the importance of providing feedback to students by listening to what students produce and then asking questions or modeling a desired response. Improvement in automatic scoring of student responses through pre-trained language models was investigated by Liu et al. (Z. Liu et al., 2023).

Kulshreshtha et al. (Kulshreshtha et al., 2022) utilized the transformer architecture for the process of generating individualized feedback during tutoring. They take the answer from the students and a manual gold standard drafted answer to generate individual feedback for the student.

Finally, Sarsa (Sarsa, 2022) delved into the capabilities of large language models in producing programming course resources. Niraula (Niraula & Rus, 2015) suggests that an automated method for judging question quality would make the question generation process much more efficient. Therefore, developing an assessment model that incorporates these factors would be necessary for a successful automatic question-generation system.

Despite these advancements, none of these studies explored the use of generative agents for automatic assessment generation and quality assurance. Generative agents to simulate human behavior are introduced by Park (Park et al., 2023). The combination of agents and prompt engineering is presenting a unique direction for future research in automatic assessment creation and is the subject of the investigation of this paper.

3. GENERATIVE AGENTS FOR ASSESSMENT GENERATION AND EVALUATION

Introduction to Generative Agents

Generative agents are advanced computational software agents constructed on large language models. These AI-powered constructs are capable of mimicking complex human activities, such as abstracting key information from voluminous texts, refining context-specific queries, or rating queries based on their relevance (Park et al., 2023).

These software agents are designed using a state-of-the-art architecture that incorporates a large language model. A notable feature of this architecture is its ability to record a comprehensive history of interactions, all encoded in natural language. Over time, these agents can convert these accumulated experiences into higher-order reflections, effectively assimilating them into their 'memory'. This repository of information can be dynamically accessed to guide future responses, akin to the decision-making process in humans (Park et al., 2023).

The underpinning of these generative agents are large language models capable of producing high-quality text in an autoregressive manner. Prime examples include the generative pretrained transformers, such as ChatGPT and GPT-4, and models like Llama and Vicuna (Chiang et al., 2023; Y. Liu, Han, et al., 2023; OpenAI, 2023).

These agents are defined and interacted with through a technique known as 'prompting'. Prompting involves presenting the agent with a specific task or query, which it then processes to generate a suitable output. This process can be further divided into zero-shot and few-shot prompting (P. Liu et al., 2021).

Zero-shot prompting is where the agent generates a response to a query without having any prior exposure or examples of the task. On the other hand, few-shot prompting provides the model with a limited number of examples, which it uses to understand and process the task (Brown et al., 2020; Wei et al., 2022).

Interestingly, the few-shot prompting technique plays a key role in defining the agent. The agent is prompted to play various roles and situations, with the context of the task feeding into the description of the agent itself. This design simulates the way humans adapt to different roles and situations based on prior experiences.

Intriguingly, each generative agent can interact autonomously with others. This interaction manifests as one agent accepting the output of another as its input, thereby fostering a collaborative intelligence network (Park et al., 2023). The development and use of these generative agents herald a significant stride forward in the field of artificial intelligence, pushing the boundaries of machine learning and natural language understanding.

Technical Parts of the Proposed System

The foundation of the proposed system rests on three large language models (LLMs): ChatGPT (specifically, gpt-3.5-turbo), GPT-4, and Vicuna 13B.

ChatGPT gpt-3.5-turbo, hosted by OpenAI and accessed through its API, is central to the refine and answer generation agent. This model is a variant of the GPT-3 model, with an architecture that includes a transformer network, featuring an attention mechanism for comprehending input context and generating sophisticated responses. The structure leverages layers of self-attention and feed-forward neural networks, allowing it to understand and generate human-like text by predicting the probability of a word given its previous words (Brown et al., 2020; Ouyang et al., 2022).

GPT-4, also hosted by OpenAI and accessible via its API, is the backbone of the rating and control agent. GPT-4 extends its predecessor by increasing its parameters, enhancing its understanding and response generation abilities. This improvement enhances its ability to manipulate and understand complex language constructs, making it more adept at providing accurate ratings and control mechanisms (OpenAI, 2023).

The Vicuna LLM 13B model, a locally hosted model based on Facebook's Llama and fine-tuned using shared GPT instruction datasets, is instrumental for question generation. As a 13 billion parameter model, it uses its expansive architecture to generate creative and diverse questions from given inputs (Chiang et al., 2023; Touvron et al., 2023).

Embeddings are another essential aspect of the proposed system. In essence, embeddings transform words, sentences, or documents into numerical vectors that capture their semantic meaning. The OpenAI embeddings are used as a foundation for this transformation (Neelakantan et al., 2022). All documents are split into chunks of approximately 1000 characters, with an overlap of 50 characters. Each chunk generates a corresponding embedding vector. These embeddings play a critical role in the similarity search, identifying the necessary text snippets in alignment with the learning goals.

The final significant component is the vector store, specifically ChromaDB.[1] A vector store is a system for storing and retrieving vectors, used in this case to store the embeddings for each document chunk. The vector store serves as a knowledge base, allowing for fast, efficient retrieval of information when the system requires access to the support material. This feature allows the proposed system to extract, analyze, and respond to inputs quickly, making it both effective and efficient in achieving its objectives.

Proposed Agent Setup, System Design, and Proposed Workflow for Generation Question and Answers

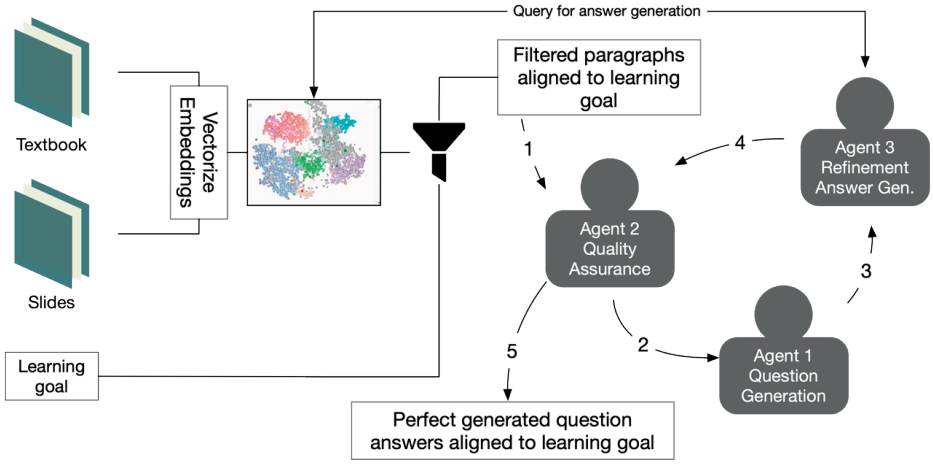

Figure 1. Illustrated representation of the interaction between agents.

Our prototype focuses on a tool engineered to function as a command line utility, programmed to accept an array of parameters. These parameters encompass documents that serve as the foundational data, the established learning objective, and a number of document sections that can be located in accordance with the learning objective.

The internal **preprocessing** of the provided documents is the base for the vector similarity search to facilitate a semantic search that selects and provides sections of the given documents from the vantage point of the learning objective (Reimers et al., 2019).

The mechanism of text vectorization is instrumental in transforming the input data. For this task, the Open AI Embeddings model is utilized (Neelakantan et al., 2022). Initially, the documents are subdivided into manageable fragments, subsequently feeding these portions into the vectorization model. The segmentation process does not rely on paragraph divisions but instead determines the chunks based on a character length of 1000 and overlapping of 50 characters with adjacent chunks.

[1] https://www.trychroma.com

The phase of document selection is employed to identify the most pertinent sections in relation to the stipulated learning objective. This is accomplished through a similarity search using cosine similarity, yielding the top n-documents, with n representing a parameter defined by the user (Mishra et al., 2020). This process employs the learning goal sentence, which is vectorized using embeddings. This resultant embedding vector is used in a similarity search against the embedding vectors of each chunk in the vector store.

Next, the document filtering phase further refines the selection by only opting for those documents with a similarity score greater than 0.8. This score is derived from the comparison between the learning goal vector and the chunk vector. This ensures that the paragraphs, which will be used as a basis for question generation, are highly focused on the learning goal. With this methodology, the input documents' size becomes irrelevant, making it capable of processing millions of paragraphs.

Quality Assurance Agent, labeled as **Agent 2**, is tasked with the evaluation of each paragraph of the selected documents based on their relevance to the learning objective. This is carried out using one of the LLM models along with an evaluation prompt. The GPT-4 model is employed for rating each paragraph on a scale from 1 to 10 (Y. Liu, Iter, et al., 2023). After this, Agent 2 delivers its output to Agent 1. (See Figure 1: Step 1)

Agent 1, the question generation agent is responsible for generating at least two questions for each highly-rated paragraph (those with a rating of 9 or above). This is accomplished with the intention of verifying the learning objective, employing a self-hosted Vicuna model for this generation task. The task is formulated by using a few-shot-prompt, enriched with the learning goal and one paragraph, repeated to as often as paragraphs rated by Agent 2 exists (see Appendix for the prompt and Figure 1: Step 2).

Subsequently, **Agent 3, the refinement and answer generation agent** based on ChatGPT, refines the generated questions to enhance their precision and alignment with the learning objective. This agent discards questions referring to figures, other chapters, code, or irrelevant aspects, replacing them with 'NaN'. Moreover, this agent generates short, precise answers for each refined question using a combination of the vector store search and few shot prompting (see Appendix for the prompt and Figure 1 Step 3).

Finally, **Agent 2 (quality assurance agent)** based on GPT-4, rates the overall quality of the generated questions and answers to ascertain if they can sufficiently achieve the learning objective again by using few-shot-prompting (see Appendix for the prompt). All generated answers along with the questions are used in a single prompt, which in turn stimulates the model in two ways. First, it rates the fulfillment of the learning goals on a scale from 1 to 10, and second, it describes the reasons for the rating (Y. Liu, Iter, et al., 2023). If the learning goal isn't fully met, the model is prompted to add more questions. (See Figure 1: Step 4)

The concluding output consists of a list of refined questions along with their answers. Lastly, during the assessment evaluation, **Agent 2 (quality assurance)** is employed to evaluate the student's answers by comparing them to the previously generated answers

from **Agent 3**. Also, here a specialized prompt to force this behavior is used (see Appendix for the prompt). The output is a rating if the question was answered correctly by the student, not correct, or if a rating is not possible. In addition, Agent 3 provides recommendations in natural language, on how the answer could be improved to guide the students in their learning progress. (See Figure 1: Step 5)

The use of GPT-4 in the quality assurance agent and the Vicuna model in the question generation agent, both cutting-edge technologies, ensures that the generated questions and evaluations align precisely with the defined learning goals. This approach highlights the system's potential for tailoring the learning process according to specific learning objectives.

Furthermore, the inclusion of the refinement and answer generation agent adds depth to the system's capabilities, enabling it to produce concise answers and refine questions for increased precision.

The use of similarity search and document filtering ensures that the focus remains on the learning objectives. This approach ensures that the content, both in the generation of questions and the evaluation of responses, remains consistently relevant and beneficial to the learning process.

4. EVALUATION

Findings

Our research findings suggest that the quality of the questions generated automatically for learning assessments is strongly dependent on the quality of the input text. We observed that the generation process consistently produces high-quality question candidates when the input text provides sufficient contextual information. Conversely, if the input document lacks the necessary information, the system refrains from generating questions.

In terms of language model performance, our observations indicate that large language models can occasionally hallucinate or generate new, irrelevant information. In our research, however, we found that the model performed exceptionally well without manifesting this behavior. We attribute this result not only to the utilization of a temperature setting of zero but also to the use of a vector store and few-shot prompting, which helped control the system's generation process.

We noted that the back-and-forth interaction between the agent was time-consuming. For a 30-page document, with a goal to generate 10 questions, the process took approximately 3 minutes for both question generation and quality assurance.

Our study consisted of 10 runs using different documents and learning objectives. All runs were evaluated by a Quality Agent, and each received a score greater than 8. This score was further corroborated by manual evaluation, where the perceived quality was in agreement with the automated rating. Despite the positive outcomes, we recommend further tests to confirm the system's ongoing quality and effectiveness for different contexts and types of documents.

Research limitations/implications

While the research demonstrates the potential of generative agents based on language models and prompting in creating assessment questions and evaluating test results, there are significant limitations and implications that need to be acknowledged.

One of the significant hurdles is the vast size of the large language models, specifically those with 13 billion parameters, equivalent to around 38 GB of data. This size exceeds the capacity of most consumer-grade GPUs, making the application of these models expensive due to the necessity for advanced hardware or cloud resources. Another obstacle is the processing speed, with models like GPT-4 being highly competent but also quite slow, which increases both computational time and costs. This factor may limit the broad usage of these models in real-time educational settings, where rapid generation and evaluation of questions and answers are crucial.

Furthermore, the present state of these models struggles to interpret and generate questions from information like formulas and figures. Their current architecture only allows to process ongoing text, where context must be included. At the moment, the content of the figures is derived by using the additional text in textbooks, which explains the figure. If this is missing the figure would not be used at all. Formular could be processed if they are provided in LaTeX code. Otherwise, they will be ignored. This makes it difficult to use these approaches in mathematics, physics, or other domains where formulas are utilized heavily.

Moreover, the effectiveness of these models depends heavily on the quality of the input data. If the source material, such as lecture slides, contains only bullet points with minimal context, the models may struggle to match them against learning goals, resulting in a failure to generate question-answer pairs.

Finally, the models don't always react as intended. The prompts need then to be refined to ensure that the models produce the expected output, adding an extra layer of difficulty and requiring a deep understanding of how to guide these models effectively. This limitation underlines the importance of continued research in this field, which affects prompt engineering and model alignment.

The current design of our generative agents primarily focuses on individual sessions rather than the entire course. This restrictive focus on session-specific learning goals, as opposed to the broader objectives of the course, might limit a comprehensive understanding of the student's learning journey. To address this, we could extend the agent's functionality by incorporating memory. This feature would allow the agent to track both the course-wide and session-specific learning objectives and retain information about students' performance. Following a model similar to Park et. al (Park et al., 2023), this memory would help the agent determine what information is relevant for long-term and short-term recall, thus better-aligning assessments with the intended educational outcomes.

Practical implications

The practical implications of this research, despite the identified limitations, are vast and transformative for educational settings.

A major benefit lies in the automation of assessments, which saves substantial time for teachers and educators. By generating questions and answers automatically, the model frees educators to focus on higher-level aspects of teaching and learning, such as the design of lesson plans, individual student mentoring, and professional development.

Additionally, the flexibility of these models allows for their application across a wide range of educational institutions and scenarios, such as elementary schools, high schools, and universities. The models could also find use in corporate environments, aiding in employee training and development programs.

Furthermore, the models empower students to take a more active role in their learning process. They can generate as many questions as they wish, enabling self-testing and reinforcing their understanding of the material. This is especially useful for remote and self-paced learning scenarios, which are common in today's digital education landscape.

Perhaps one of the most exciting prospects of these models is their potential to facilitate individualized learning. By generating focused questions and evaluating responses, they can provide personalized feedback and recommendations. This adaptability could help in meeting diverse learning styles and needs, paving the way for more personalized and effective teaching methods.

Originality/Value of the paper

The originality and value of this research lie in its innovative application of agent-based systems for educational assessment generation and evaluation, an area that, to the authors' knowledge, remains largely unexplored.

The paper demonstrates that the setup of such agents, using large language models like Vicuna, ChatGPT, GPT-4, and prompting techniques, is a feasible and promising approach. It sheds light on a novel path of employing advanced AI technologies to assist educators and learners, providing a blueprint for future developments in this field.

In conclusion, the innovative design of this system is highly promising for the future of automated learning and assessment tools. The combination of a comprehensive document processing approach, and advanced AI Agents including automatic refinement and quality assurance tasks, makes this utility a formidable tool in educational settings. It is worth noting that this advanced system also demonstrates the potential for adaptation and further improvements to meet evolving educational needs and challenges in the future.

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APPENDIX

Prompts

Rate Paragraphs regarding the learning goal

> Please rate the following paragraph on a scale from 1 to 10, where 1 means that the paragraph is not relevant to the learning goal and 10 means that the paragraph is very relevant to the learning goal. Be precise in your rating. If you are not sure, please rate the paragraph with lower than 5. Give only integer values as rating, no text or explanation.
>
> Learning Goal: {{goal}}
>
> Paragraph: {{paragraph}}

Generate Questions:

> In order to check whether students have achieved the learning goal below, at least two questions must be generated for the given section with the aim of verifying the learning goal.
>
> Learning Goal: {{goal}}
>
> Section: {{section}}
>
> Questions:

Refine Questions:

> Refine the following questions to make them more precise and aligned with the learning goal. Ensure that the original meaning of the question is not changed. Make sure that the questions are not too broad and are focused on the learning goal. Ensure that no reference to figures is asked. If so, remove the question and respond with “NaN”. If the question is not relevant to the learning goal, also remove the question and response with “NaN”.: Make sure that no references to other chapters or code are made. If so, remove the question and respond with “NaN”.
>
> Learning Goal: {{goal}}
>
> Questions: {{question}}
>
> Refined Question:

Overall Rating for all Questions and Answers toward the learning goal

> Given a dict of questions and answers, please rate the overall quality of this set of questions and answers as sufficient to achieve the learning goal. Rate this by a number from 1 to 10, where 1 means that the set of questions and answers is not sufficient to achieve the learning goal, and 10 means that the set of questions and answers is sufficient to achieve the learning goal. Be precise in your rating. If you are not sure, please rate the set of questions and answers lower than 5.
>
> Describe the reasons for your rating in a few sentences. If the rating is lower than 9 add 2 questions to close the gap.
>
> Learning Goal: {{goal}}
>
> Questions and Answers: {{qa}}

Prompt Evaluation of Student Answers:

> 'I give you the context, question and answer. Rate the answer by giving out the probabilities for the classes in a new line, with the probablities between 0 and 1. The classes are - Contradiction, Neutral and Entailment. Also give the reason for the rating.
>
> Give me the output in a json string consisting of {"contradiction":value, "neutral":value,"entailment": value, "reasoning_behind_grading": value}.
>
> The reasoning must be in German containing the reason for the score given and how the answer can be improved. Only json string output will be accepted, no additional text. The sum of the probabilities of all the classes should be 1.'

Example Output

############## File to be loadded ##############

data/example_ai.txt

Loaded data from file size: 43

############## Generate VectorStore ##############

############## Documents are Vectorized ##############

############## Search relevant Parts for LG ############

Learning Goal: As a Student, I would like to understand the interconnection between Agents and Environments!

Selected Documents: 10

------ Document ------

2.1: Agents and Environments

An agent is anything that can be viewed as perceiving its environment t.... Score: 0.5231937766075134

------ Document ------

In Figure 2.5, we have sketched the basic PEAS elements for a number of additional agent types. Furt.... Score: 0.7983673214912415

------ Document ------

Chapter 1 identified the concept of rational agents as central to our approach to artificial intelli.... Score: 0.8482365608215332

------ Document ------

The code repository associated with this book (aima.cs.berkeley.edu) includes implementations of a.... Score: 0.8700109720230103

------ Document ------

Single agent vs. multiagent: The distinction between single-agent and multiagent environments may se.... Score: 0.8834455609321594

------ Document ------

We can imagine tabulating the agent function that describes any given agent; for most agents, this w.... Score: 0.9547677040100098

------ Document ------

2.3.2 Properties of task environments

The range of task environments that might arise in AI is obvio.... Score: 0.9721614122390747

------ Document ------

Now that we have a definition of rationality, we are almost ready to think about building rational a.... Score: 0.9741522073745728

------ Document ------

To illustrate these ideas, we use a very simple example—the vacuum-cleaner world shown in Figure 2.2.... Score: 0.9888737201690674

------ Document ------

Consider the simple vacuum-cleaner agent that cleans a square if it is dirty and moves to the other .... Score: 0.9888757467269897

############## Documents are selected ##############

Filtered Documents: 8

############## Documents are filtered ##############

############## Rate Paragraphs regards the learning Goal ##############

Paragraph: Chapter 1 identified the concept of rational agents as central to our approach to artificial intelli.... Score: 0.8482365608215332.... Rating GPT35: 9 Rating GPT4: 10

Paragraph: The code repository associated with this book (aima.cs.berkeley.edu) includes implementations of a.... Score: 0.8700109720230103.... Rating GPT35: 9 Rating GPT4: 9

Paragraph: Single agent vs. multiagent: The distinction between single-agent and multiagent environments may se.... Score: 0.8834455609321594.... Rating GPT35: 8 Rating GPT4: 8

Paragraph: We can imagine tabulating the agent function that describes any given agent; for most agents, this w.... Score: 0.9547677040100098.... Rating GPT35: 7 Rating GPT4: 9

Paragraph: 2.3.2 Properties of task environments

The range of task environments that might arise in AI is obvio.... Score: 0.9721614122390747.... Rating GPT35: 9 Rating GPT4: 8

Paragraph: Now that we have a definition of rationality, we are almost ready to think about building rational a.... Score: 0.9741522073745728.... Rating GPT35: 9 Rating GPT4: 9

Paragraph: To illustrate these ideas, we use a very simple example—the vacuum-cleaner world shown in Figure 2.2.... Score: 0.9888737201690674.... Rating GPT35: 9 Rating GPT4: 9

Paragraph: Consider the simple vacuum-cleaner agent that cleans a square if it is dirty and moves to the other .... Score: 0.9888757467269897.... Rating GPT35: 9 Rating GPT4: 8

############## Paragraphs are rated ##############

Filtered Documents: 5

############## Generate Questions ##############

Paragraph: Chapter 1 identified the concept of rational agent.... Score: 0.8482365608215332.... Rating GPT35: 9 Rating GPT4: 10 Questions GPT35: 1. What is the concept of rationality and how is it applied to agents operating in different environments?

2. How do properties of an environment influence the design of suitable agents for that environment?

Paragraph: The code repository associated with this book (aim.... Score: 0.8700109720230103.... Rating GPT35: 9 Rating GPT4: 9 Questions GPT35: 1. What is the purpose of the general-purpose environment simulator in the code repository associated with the book?

2. Why is it important to evaluate agents in multiple environments drawn from an environment class rather than just a single environment?

Paragraph: We can imagine tabulating the agent function that .... Score: 0.9547677040100098.... Rating GPT35: 7 Rating GPT4: 9 Questions GPT35: 1. What is the difference between the agent function and the agent program?

2. How can we construct the table that describes the agent function for a given agent?

Paragraph: Now that we have a definition of rationality, we a.... Score: 0.9741522073745728.... Rating GPT35: 9 Rating GPT4: 9 Questions GPT35: 1. What is a task environment and why is it important for building rational agents?

2. How does the flavor of a task environment affect the design of an agent program?

Paragraph: To illustrate these ideas, we use a very simple ex.... Score: 0.9888737201690674.... Rating GPT35: 9 Rating GPT4: 9 Questions GPT35: 1. What is the vacuum-cleaner world and why is it useful in illustrating the interconnection between agents and environments?

2. Can you explain the agent function described in Figure 2.3 and how it relates to the vacuum agent's actions in the environment?

############### Refine Questions ###############

Question: What is the concept of rationality and how is it applied to agents operating in different environments?.... Refined Question GPT35: How is the concept of rationality applied to agents in different environments and what is its significance in understanding the interconnection between agents and environments?

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Question: How do properties of an environment influence the design of suitable agents for that environment?.... Refined Question GPT35: What factors of an environment should be considered when designing an agent to operate within it?

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Question: What is the purpose of the general-purpose environment simulator in the code repository associated with the book?.... Refined Question GPT35: How does the general-purpose environment simulator in the code repository associated with the book facilitate the interaction between agents and environments?

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Question: Why is it important to evaluate agents in multiple environments drawn from an environment class rather than just a single environment?.... Refined Question GPT35: How does evaluating agents in multiple environments drawn from an environment class help in understanding the interconnection between agents and environments?

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Question: What is the difference between the agent function and the agent program?.... Refined Question GPT35: What is the distinction between the agent function and the agent program in terms of their roles in the interaction between agents and environments?

--

Question: How can we construct the table that describes the agent function for a given agent?.... Refined Question GPT35: What are the components of the agent function and how do they interact with the environment?

--

Question: What is a task environment and why is it important for building rational agents?.... Refined Question GPT35: What is the role of a task environment in the design and implementation of rational agents?

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Question: How does the flavor of a task environment affect the design of an agent program?.... Refined Question GPT35: How does the type of task environment influence the development of an agent program?

--

Question: What is the vacuum-cleaner world and why is it useful in illustrating the interconnection between agents and environments?.... Refined Question GPT35: How does the vacuum-cleaner world illustrate the interconnection between agents and environments?

--

Question: Can you explain the agent function described in Figure 2.3 and how it relates to the vacuum agent's actions in the environment?.... Refined Question GPT35: NaN

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############## Generate Answers ##############

[{‘question’: ‘How is the concept of rationality applied to agents in different environments and what is its significance in understanding the interconnection between agents and environments?’, …

############## Answers are generated ##############

############## Overall Rating if Learning Goal is achievable ##############

Overall Rating GPT4: Rating: 8

Reasons: The set of questions and answers provided covers a good range of topics related to the interconnection between agents and environments. It discusses the concept of rationality, factors to consider when designing an agent, the role of task environments, and the distinction between agent functions and agent programs. However, there are a few areas that could be improved to achieve a more comprehensive understanding of the topic.

Additional Questions:

1. What are some common types of environments, and how do their properties affect the design of agents?

2. Can you provide examples of different agent architectures and how they are suited for specific types of environments?

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CBL TO REVITALIZE DEEP APPROACH LEARNING OF DECISION–MAKING METHODS

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ABSTRACT: The use of active methodologies in teaching allows students and teachers a profound change in the way they face the teaching-learning process. The traditional approach where the teacher focuses his effort on the content ceases in favour of a new approach in which the student learns by own experience and decision, reinforcing the deep approach to learning. This is essential for some areas of knowledge, such as decision making. A student cannot face a business decision making if he is not aware of how it works. The use of learning based on challenges, applied to a designed experiential activity, allows the student to feel immersed in the business process, in such a way that they pose their own challenges and thereby develop their learning capacity. The support of virtual technologies like beer factory simulator software, increases this motivation. On this occasion we have designed a simulation activity of a beer bottling factory where students set their own challenges and make decisions according to their objectives, playing inside a virtual factory designed in Factory.io. The article describes the procedures to be able to reproduce this activity, as well as the results obtained in the exercise of the activity.

KEY WORDS: *CBL; deep approach learning; decisionmaking.*

1. INTRODUCTION

Learning the methods and tools for business decision-making in the academic field is a challenge for teachers. As a general rule, it is a very difficult process for experienced people, and a level of technical training should be provided to people who have never lived in a business environment. The students lack professional experience that prevents the correct transmission of concepts and procedures. As a consequence, the student follows certain instructions, but does not achieve deep learning.

The Master's Degree in Product and Service Management (MGEPS) has generally had activities developed under Kolb's Experiential Learning Activities (ELA) methodology (Gadola & Chindamo, 2019), since we consider that innovation in educational processes

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it is completely necessary. For decision-making subjects, students rely on assumptions; or, if this is the case, in which they have received training in decision-making during the first four-month period, they base them on data collection. As the students are very heterogeneous, the development of the activity is complicated.

Thus, the need to search for new active methodologies to counteract this variability in the group was determined. The challenge-based learning (CBL) methodology involves students from the beginning, starting with a real problem that is simulated in the learning context (Nichols & Cator, 2008). The students determine the challenge from a series of indications given by the teacher, so that the ideas do not wander (Gaskins & Johnson, 2015).

It was decided to apply this teaching methodology to an activity in which the students work simulating the beer filling and packaging process. With the experience of this process, they are presented with a new challenge to solve problems occurred in a virtual factory. In the process, decisions must be made within the uncertainty of not knowing how the process will turn out with a new formulation. Training in decision making is achieved through the questions and actions taken.

Additionally, some virtualization software, like Beer Factory (AKEL, 2023), permits the student to live a real factory situation, in which they "watch" and "feel" the problems occurring in the factory. We implemented this activity using that software.

In this article we show the indications to be able to reproduce the experience, as well as the conclusions obtained from ours. The theoretical concepts developed, the methodology used and the minimum resources necessary for its reproduction are described.

2. METHODOLOGY

Hypothesis and objectives

The starting hypotheses with which the study is to be carried out have the following objectives to improve the subject:

1. Change the activity from the ELA modality to a CBL methodology.
2. Determine if the new activity favors the required learning.

Based on these objectives, the following research question is launched:

RQ: What is the impact of the CBL on the motivation of the Master?

Description of the activity

The activity is organized in 2 sessions of 2 hours and 30 minutes. At the beginning of each session, the methodology to be used is described, indicating how to proceed throughout the activity.

The first session the students are involved in the factory process, using Factory.io. The students learn about the process, and the teacher explains how the performance of the factory goes. Herewith, it is established as a work object (Big Idea) to create a new solution regarding the process to improve the process. As it is the first time we proposed the challenge, we looked for a funny process, and we decided to simulate "duff" brewery (Homer Simpson's most tasted beer). A screenshot of the simulator can be seen in Figure 1.

Figure 1. Beer factory simulator. *Source: CreativeForge Games*.

Then work in phases of determined time following the CBL scheme. As support, the students have a poster (Figure 2) where they are reminded of the phases.

From this idea, the students raise essential questions, so that they are able to determine the needs and scope of the activity. Questions such as "What do we have to do…? they are not answered. The object of this phase is to determine what needs our big idea (Big Idea) requires so that the challenge is established. The challenge of each group is coordinated with the teacher, so that it makes sense not to wander in the performances.

With the determination of the challenge, the most critical phase of the learning process begins. This starts on session 1. The teacher acts as a guide, but he must do it correctly so that the students can learn. Thus, the "guiding" questions that arise must be related to the theme of the activity. The teacher must provoke this creation of questions.

Figure 2. Reminder poster of the stages of the activity.

To be effective, a series of guided activities (guiding activities) must be carried out that allow the student to deepen the subject of study. The following activities are proposed: Analyze the load/unload process of the malt; determine the format of the bottle and tack-time; measure time and productivity; Determine the main factor to be assessed.

Students have additional resources on the internet that help them determine the questions needed to meet the challenge. In addition, they are provided with ex-professional tools for decision-making. The most delicate moment is the selection of solutions. Each question, activity, and any decision taken results in a series of actions and solutions to be applied. Here the activities carried out are valued. The evaluation of the solutions leads to a single final decision.

Finally, at the end of the second session, the students disseminate their work to other classmates and groups that value the work done. The presentation and the solution adopted are valued. This is part of the evaluation of the subject, so the students put a lot of effort into doing it.

Assessment instruments

The activity ends with a survey that assesses the RQ proposed at the beginning of the section. For this, the Motivational Diagnosis Instrument for Engineering Education (MDI-EE) has been used, described in (López-Fernández et al., 2015), with a scale of values from 1 to 4. This is compared with a previous survey carried out on the students and the increase is valued. in the analyzed dimensions. The sample has been 18 students.

3. RESULTS

The compilation of the survey results are shown in Table 1. The means are used to show the values of the indicators used.

Table 1. Mean of the indicators of the MDI-EE survey carried out.

Status	M1	M2	M3	M4	M5	M6	MGen
Pre	3.15	2.05	1.87	3.03	3.12	2.76	3.01
Post	3.62	2.72	3.13	3.08	3.25	2.99	3.70

It is observed how in general the values of the indicators increase. The MGen indicator of general motivation increases from 3.01 to 3.70, demonstrating that the activity has been motivating for the students. A more exhaustive analysis of the indicators provides the information that the willingness to study (M3) and the perception of reward for the effort made (M2) are the ones that have increased the most.

4. CONCLUSIONS

The use of the CBL methodology in the subject of product development in MGEPS has reinforced the learning of the students, but, above all, the motivation. The basis of the study indicates that the student's willingness to study increases, and that it is reinforced with the rewards they obtain. This indicates that the activity has been correctly planned and the tools (the game was delighting) have been accurately selected. It should be extended to other activities of the same nature. Following the educational innovation project in which the group of authors is immersed, this technique will be implemented in other activities of the same subject, even others. The study has the limitation that it has only been implemented in one course, but similar results are expected in future courses.

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THE RACE FOR CHINA EXPERTISE

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ABSTRACT: "China expertise" has become the keyword in European foreign politics. A look at the latest government publications shows that a clear definition is yet to be expected. It can be summarized from reports about educational programs that there are differing trends among European countries as regards their Chinese language and other China-related skills as well as their infrastructures to gain these. A focus is laid on Germany, Europe's biggest economy. A linguistic assessment shows that an early onset of acquisition is recommended for learning this distant language. Given the almost pan-European desire for China expertise, a clear definition is demanded so efficient international cooperation to build up this expertise over-regionally is possible.

KEY WORDS: *China; competence; China expertise; China strategy.*

1. INTRODUCTION

The increase of hard power exerted by the People's Republic of China ("China" hereafter) led to a shift in attitude toward the country that is now seen as "an economic competitor and a systemic rival in an increasing number of areas" (European Parliament, 2021: L1a) by many Western governments. Voices suspicious of Chinese soft power strategies were heard as early as 2006 (Paradise, 2009; Starr, 2009). German chancellor Scholz was the first European head of state to visit China after the 20th party congress, and as he was accompanied by a business delegation, there seems to be an interest in at least maintaining economic ties, if not strengthening them. At the same time, the People Daily forecasts in January that in 2023 foreign trade and foreign investment are to be stabilized (Qu, 2023). Chances are high that many businesses in Europe, particularly in its biggest economy Germany, will have some kind of relationship with Chinese partners. It is, therefore, highly advisable to gain the China expertise demanded by European governments.

This paper aims to give an overview of the status quo of China expertise in various European countries, as data are available in July of 2023, with a special focus on Europe's biggest economy Germany and one of its stronger federal states, Bavaria. It draws on declarations of European Governments, statistical information on different related competencies, and descriptions of these by scholars from various fields, thus compiling

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data necessary for the elaboration of a China expertise strategy. Findings include remarkable differences in the availability and development of related skills between countries. Arguments from a linguistic point of view for early language education are put forward. Implications are a recommendation for strengthening Chinese as a subject from the primary level and China-related topics from the secondary level as well as more over-regional exchange. Firms, educational institutions, and political decision-makers are addressed by this interdisciplinary approach to the question of how to build up China expertise. The remainder of the article is structured as follows. Section two presents definitions of China expertise. Section three summarizes the status quo of knowledge about China, whereas section four focuses on Chinese language skills. Section five points out linguistic particularities of the language before section six concludes the paper with recommendations.

2. THE (MISSING) DEFINITIONS OF CHINA EXPERTISE

China expertise has become the declared desideratum of European Governments. The German government announced in its coalition pact of 2021 to work out a comprehensive China Strategy (SPD, Green Party & FDP, 2021: 157). France demands a strategic vision on China to recalibrate its bilateral relations (French National Assembly, 2022). The UK also asks for a China strategy and China expertise (Great Britain & HM Government, 2021: 22). Yet in other countries, such as Spain, there is no concern for this on the official level. In calls for China strategies, it remains unclear who needs what kind of skills and knowledge. Most of these entities have yet to come forward with a comprehensive outline of a China Strategy, and there is no clear definition of what China Expertise comprises.

The European Parliament "calls on the EU […] to develop a programme to finance China-related research and language training in the EU" (article 67) and "[p]oints out the need to introduce, independently from the C[ommunist] P[arty of] C[hina]'s influence, programmes for the study of Chinese culture, language and politics" (article 68) (European Parliament, 2021). The German Federal Ministry of Education and Research (FMER) does not define China expertise itself but offers a description of measures it supports to build up China expertise. Besides a database to document expertise, these include "[e]stablishing long-term structures for cooperation and networking between scientists and researchers in both countries" and "[s]upport measures for the targeted acquisition of China-related knowledge and Chinese language skills for key stakeholders at schools, universities and in science" (Federal Ministry of Education and Research of Germany, n.d.: section "Initiatives for the development and expansion of China expertise in Germany"). In early July, the long-awaited China Strategy was finally presented (Federal Government of Germany, 2023). Chinese language skills are mentioned before intercultural competence and knowledge about culture and civilization and other things (p. 61). In its outspoken recommendations, the French National Assembly proposes to finance the improvement of understanding of China but fails to mention language skills, except for somewhat undefined general recommendations. Although some voices ask for it (Parton, 2020), the UK government has no official position paper on its relation with

China. However, Foreign Minister Cleverly made clear that engagement with China is an obligatory part of UK policy (Cleverly, 2023). As we can see, language skills are often listed last, play a minor role in descriptions of desired China expertise, or are not mentioned.

3. THE STATUS QUO OF CHINA EXPERTISE

A 2020 report by the Expert Commission for Research and Innovation EFI of the FMER (Kooperation international, 2020) finds that language and cultural knowledge, as well as knowledge about markets, the institutional framework, and the political structure necessary for a constructive exchange with China, are scarce in Germany. The MERICS report on the topic (Stepan et al., 2018) summarizes a lack of basic language skills and a lack of basic understanding of the underlying political and power structures, knowledge of state plans, the legal framework and resources for funding. Baron and Yin-Baron even call knowledge about China in Germany „breathtakingly deficient" (Baron & Yin-Baron, 2018: 21). This specialized knowledge can be gained at almost 30 German universities that offer Chinese Studies or sinology degree programs. The number of students of sinology is low (494 started in 2016) and in decline (Stepan & Frenzel, 2020: 245) at the 32 universities in German-speaking countries (Fachverband Chinesisch e.V., n.d.). There are approximately 1,400 cooperation programs between German and Chinese universities (German Rectors' Conference, 2022), with declining numbers. The 19 Confucius Institutes in Germany used to offer summer schools in China before the pandemic. The outcome of incentives for students of other degree programs to gain China expertise, such as a certificate upon completing an additional workload in China studies, is yet unclear (cf. University of Bayreuth, n.d. about this certificate). China-related topics are not yet a compulsory part of German schools' curriculum, (Stepan et al., 2018), but in 2020, the private Mercator Foundation and the Goethe Institute founded the Educational Network China which aims at building up China expertise at schools.

There are 19 Confucius Institutes and three Confucius Classrooms in Germany (Konfuzius-Institut an der Universität Heidelberg e.V., n.d.) where knowledge about China can be gained through workshops, exhibitions, and lectures. However, given various negative reports in the media about possible political influence, their offer suffers very limited acceptance (for the related topic of China's image in German media see Baron & Yin-Baron, 2018; Jia et al., 2021; Robak et al., 2020). Some think tanks, in part co-funded by governmental institutions, are able to offer China expertise through events that are often free, e. g. MERICS[1]. Also, some chambers of commerce offer paid events directed at business people less regularly. There are also organizations on the local level: In Bavaria, e. g., a "financially independent and politically neutral organization" that call themselves an association for economy and culture in Chinese, offers talks, workshops, and events approximately every fortnight (Chinaforum Bavaria, n.d.), including special and general topics about economic and legal issues to anyone having or looking for ties

[1] https://merics.org/en

with China. Three more private lifelong learning companies offer China-specific training on a course finder registry in urban areas in Bavaria. The Bavarian university law allows anyone interested in courses to enroll as a guest student (Bavarian State Chancellary, 2022), similar to other federal states.

The headquarters homepage of Confucius Institutes (中国国际中文教育基金会 [China International Chinese Education Foundation], n.d.) lists 214 entities in 39 European countries, including Confucius Classrooms and other forms of representations. The UK leads the list with 34 institutes, followed by Germany (22), France (18), Italy (14) and Spain (9). Many of them are facing the reputational difficulties mentioned above. The EACT[2] currently provides information on France, Spain, Hungary, Belarus, and Russia from 2017, but no up-to-date numbers of universities that offer sinology. An international European cooperation about getting China expertise is yet unknown. The European Network on China ETNC[3] studies EU-China relations and facilitates exchange among researchers, with participation by institutions from 19 European countries[4]. Unfortunately, there are no other figures from trustworthy sources.

Separate from China expertise, there is an infrastructure to provide Chinese language skills.

4. CHINESE IN GERMANY AND BEYOND

Chinese is slowly becoming an established subject at schools in Europe, with remarkable differences between countries. In Germany, the number of students of Chinese has been stable for years at roughly 5,000 in 2018 (Stepan et al., 2018: 10), that is of 8.4 million students at German schools (in 2021; DeStatis, 2022). Among 18 primary, 102 secondary, and 10 vocational schools, some offer Chinese as a core subject and some federal states include it optionally in graduation exams (Fachverband Chinesisch e.V., n.d.-b). Around 250 to 300 schools offer exchange programs with China, and the number of around 3,000 (teenage) students taking part in these (Frenzel & Stepan, 2019: 18) is declining (Stepan & Frenzel, 2020: 248); many exchange programs have been canceled for the long term (personal communication with secondary schools in Middle Franconia). Of the seven German universities that offer a teaching of Chinese degree program, two have a chair for this discipline. Only four federal states offer the secondary state examination after a two-year practical training granting the right to teach Chinese at schools. Eleven out of sixteen federal states have a curriculum for Chinese at secondary schools. Both the type (whether it is offered as an additional, elective or core subject) and the scope (the number of teaching periods per week and consecutive years of instruction) of Chinese language training in sinology and China studies programs vary considerably (Guder & Burckhardt, 2021; Klöter, 2016), which is also true for schools. At many universities,

[2] https://www.ouhanhui.eu/#:~:text=The%20European%20Association%20of%20Chinese%20Teaching%20(EACT)%20is%20an%20international,to%20provide%20research%20on%20the

[3] https://etnc.info

[4] Austria, Belgium, the Czech Republic, Denmark, Spain, Finland, France, Greece, Hungary, Italy, Latvia, Germany, the Netherlands, Poland, Romania, Slovakia, Sweden, Switzerland, and the UK

Chinese language training has almost wholly been outsourced to Confucius Institutes, in part due to a lack of funds for professional staff. The Educational Network China kick-off event was held in late August of 2022, including an exchange with a French education expert. There seems to be a general trend toward a decline in Chinese language skills, and a systematic over-regional educational infrastructure is not discernible.

In comparison, 46,000 students learned Chinese at over 660 public schools in 2018 in France (Guder et al., 2021: 6), including 68 primary schools (Confucius Institute France, n.d.), as the country has traditionally been at the forefront of Chinese studies in Europe (cf. Starr 2009). The UK seems to accelerate its pace of teaching Chinese with the Mandarin Excellence Programme that exceeded its goal in 2021: 6,274 students were learning Chinese at 71 schools in 2021 (Nicoletti & Culligan, n.d.); Italy is catching up even faster (Masini, 2023). More than 200 primary and secondary schools offered elective Chinese courses in Spain in 2019 (The People's Daily, 2019). According to the Confucius Institute of Barcelone (2018), one university offered a teaching of Chinese degree program supported by Hanban in the UK, France, Spain and the Netherlands respectively. Further numbers are not available. International exchange in Chinese language teaching exists to some degree, also through the European Association of Chinese Teaching, which organizes symposiums.

Generally, the importance and benefits of Chinese language skills seem to be underestimated in international business (IB). This judgement is based on various literature reviews of investigations into Chinese in IB and Business Chinese (in preparation by the author of this paper).

5. THE PARTICULAR CASE OF CHINESE AS A FOREIGN LANGUAGE

Chinese is a distant language (Guder, 2005b, 2008). Linguistically distant means that it is genetically (by its origin) and typologically (by its language type) unrelated to Indo-European languages such as English and German. Contrastive linguistic error analysis assumes that very different languages (e. g. distant languages) are relatively difficult to learn (Fries, 1945; Lado, 1957). Universalist linguistic views such as the Markedness Differential Hypothesis (Eckman, 1977), the Naturalness Differential Hypothesis (Schmid, 1997), and the closely related Structural Conformity Hypothesis (Eckman, 1991), use universal language structures (preferred by all languages) as tertium comparationis, and they conclude that very different languages are likely to take more effort to learn. There are most likely more structural differences in the respective language pairs of first and target language. The Foreign Service Institute (FSI) of the U.S. Department of State proposes a similar definition and measure of linguistic distance used in some research considering the distance between languages. It uses a score based on learning difficulty that ranks languages according to the average time needed to reach a certain level of proficiency or the proficiency reachable in a certain amount of time (cf. U. S. Department of State, Foreign Service Institute, n.d.). There are no grounds to assume that linguistic distance causes the same level of learning difficulty in both directions: It may be easier for native

speakers of language A to learn language B than it is for native speakers of language B to learn language A, which is why the neutral tertium comparationis of universal linguistic preferences was introduced by the theories mentioned above. Suppose one language differs only slightly from universal preferences, and another shows many more diversions from these. In this case, this language pair will most likely be characterized by an imbalance in learning difficulty. The Chinese language has categories such as phonological tone and a fundamentally different writing system that need to be newly acquired by Western learners. This is why it takes native speakers of Indo-European languages longer to reach the same level of command of Chinese compared to a relatively closely related Indo-European language that shares most of the linguistic categories. Due to this structural and an additional pragmatic distance, Chinese does not fit the Common European Framework of References for Languages (CEFR). Comparable descriptors for Chinese were elaborated by experts on Chinese language teaching (Guder, 2015), and it is suggested that for adult native speakers of German more than 3,000 teaching periods are required to reach an advanced level of Chinese, corresponding to the level C2 of the CEFR; or 2,200 teaching periods for native speakers of English for professional working proficiency according to the FSI. It becomes clear from the mentioned sources that mastering Chinese is possible. Also, using digital language production resources facilitates learning Chinese and one of its most challenging aspects, the Chinese script. In a survey among 40 teachers of Chinese at German schools (Guder & Burckhardt, 2021), approximately two-thirds agreed that their students successfully reach the level A1, around half of them can guarantee the level A2. The picture becomes much more complex at B1 level, since different language skills were asked about separately (i. e., speaking, writing, and other skills, actively and passively). Given the limitations of the institutional framework for teaching Chinese, only about ten percent of the teachers agree that their students reach B2 level. The interviewees indicated between one and five teaching periods per week and between two and nine consecutive years of tuition. With 36 weeks of tuition per school year, an average of three weekly teaching periods adds up to roughly 100 periods per school year, so an advanced level could be reached after 30 years of tuition. This would be reachable within three years of intensive courses in China (cf. Guder, 2005a: 68). We can conclude from these figures that an early professionalized language education is necessary to realistically reach a sound operative level of Chinese language skills that can serve as a vantage point from which to intensify and specialize. It remains unclear if and to what extent children might learn Chinese at a faster pace since the trade-off between more plasticity in the brain among younger learners against a more cognitive learning style among older learners is not yet fully understood as regards learning a distant language (see Herschensohn, 2013, who summarizes advantages for younger learners, and results on pronunciation by Cenoz, 2005, among many studies).

6. CONCLUSIONS AND IMPLICATIONS

Some countries like Italy and the UK are fast in developing their structures for building more China expertise, particularly linguistically. The opposite seems to be the case in Germany. Since it requires relatively more time to become fluent in Chinese, countries

are well advised to start Chinese language education at the earliest possible age. Given the close economic ties with China, Chinese language skills may serve as communicative facilitators and contribute to successful business relations. Studies show how language barriers hinder business abound (Bilro & Cunha, 2021; cf. Harzing et al., 2011; Tenzer & Schuster, 2017). Other types of knowledge and skills are equally important to get the desired yet underdefined China expertise. Also in this regard a swift decision-making is an urgent recommendation. Introducing China-related topics at secondary school curriculums is a desirable start. Since China expertise is a strategic interest of various European countries, more international cooperation guided by clearly defined strategies to transfer knowledge about China within Europe is necessary. Initial steps were already made, the necessary networks are there, and measures could be intensified through a strong European network of think tanks and governmental institutions to create synergies.

7. LIMITATIONS AND FUTURE RESEARCH AGENDA

Detailed data on the availability of Chinese language skills among European firms are scarce, and only a fractioned picture of China expertise is possible. The same is true for up-to-date figures from education. The sources were limited to trustworthy official sources such as government reports. This is why the future research agenda includes the following steps: A thorough analysis of available Chinese language skills and China-related knowledge in education as well as outside the education sector in at least one representative area, and an assessment of the repercussions of these skills and knowledge.

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CONFLICT OF INTERESTS

The sole author of this paper is head of the China Competence Center of Ansbach University of Applied Sciences.

AUTHOR CONTRIBUTIONS

The sole author of this paper is fully responsible for it.

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BOOSTING STUDENTS' ACHIEVEMENT RATE ON MOOCS

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ABSTRACT: This work is part of an Educational Innovation and Improvement Project developed at the UPV. Our analysis is the first step to apply strategies that could improve the learning involvement of students in two EDx-UPV MOOCs: "Strategy and innovation in public administrations" and "Public policies and accountability", which are offered separately or together as a Professional Certificate. These are courses in which the enrollment is very high but few students finish them completely, for this reason we converted a first long one into two shorter. The completion rate has been slightly increased and the dropout rate decreased, however, we need a higher student retention. Based on the review of questionnaires proposed by the literature and surveys from previous editions, other surveys have been proposed in this edition aimed at finding out the reasons that lead them to complete the course, as well as the difficulties encountered in its execution. With this information, we observe that the satisfaction of those who finish is very high, but a greater motivation and involvement of the student is necessary through communication, interaction and direct feedback with the teacher, and among the students themselves, both on the course platform and through social networks.

KEY WORDS: *MOOC (Massive Online Open Course); retention; motivation; involvement; communication.*

1. INTRODUCTION

The purpose of this paper is to analyse how to improve the involvement of the students in the learning process of two MOOCs ("Strategy and innovation in public administrations" and "Public policies and accountability"), which are offered through the EDx platform, and fully complete the educational program that is proposed. Both courses have obtained the UPV 2021-2022 Network Teaching Award for MOOCs and have received the distinction "Strategy, policies, innovation and accountability in public administration" Professional Certificate from EDx

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(https://www.edx.org/es/professional-certificate/upvalenciax-estrategia-politicas-innovacion-y-rendicion-de-cuentas-en-la-administracion-publica). In addition, they have been approved by the Valencian Institute of Public Administration (IVAP).

As a first step, we have analyzed the literature and the surveys carried out by the UPV, completed by the students in previous editions, seeking possible explanations for their continuity until its completion or abandonment. With this information, other surveys have been built with specific questions to the students of a new edition, particularly aimed at finding out the reasons that led them to complete the course, as well as the difficulties encountered in its execution. Based on this information, some strategies will be designed to promote informal interaction and feedback between the teacher and the students, and among them, in the coming courses. In addition, the improvements obtained will serve, on the one hand, to be better prepared in the event that we need to teach some subjects online or through new MOOCs and, on the other, to improve the different communication channels of these subjects.

2. RELATED WORK

According to the literature, the dropout problem in this type of course is a common fact (Yamba-Yugsi & Luján-Mora, 2017), and the reasons why students drop out of MOOCs are varied, such as: low motivation (Khalil and Ebener, 2014), excessive learning pace or workload (Martín Rodriguez et al., 2013; Zheng et al., 2015), low cost (Aldowah et al., 2020), course design or quality of its contents (Onah et al., 2014; Yousef et al., 2014), excessive complexity (Ferguson and Clow, 2015), low interaction and communication between students (Arias et al., 2019; Rosé et al., 2014; Yang et al., 2014) or poor or limited feedback (Jordan, 2015). In addition, there are other personal, family or circumstantial factors (Aldowah et al., 2020) that are more difficult to influence, a priori, including lack of time (Itani et al., 2018).

But what is behind this lack of time as a declared reason for abandonment? Given that time is a limited resource, and its allocation is a matter of priorities, so that the student prioritizes, as far as possible, taking the course over other activities or use of their time, their motivation must be enhanced, both involvement and commitment to it, because it is essential for the success of teaching (Sinatra et al., 2015). In this sense, a more interactive teaching context, which encourages participation and interaction and grants a more leading role to the student in the construction of learning, can contribute to a greater motivation and involvement of the student in its different aspects (Garcia-Ortega et al. al., 2021). In fact, various investigations suggest that personal accessibility, communication and interaction, and direct feedback from the teacher with the students and among the students themselves, which do not occur naturally and spontaneously in a MOOC, are the main aspects that students value in favor of face-to-face teaching compared to modalities with a greater online component (Woo & Reeves, 2007; Bonk & Graham, 2012; Galan-Cubillo et al., 2021). Thus, they are fundamental aspects to address in the field of online teaching. In the same line, authors such as Moore and Fetzner (2009) report that the support provided to students through social interaction and communication on networks contributes to reducing the dropout rate.

3. METHODOLOGY

The course that this project takes as its starting point was entitled "Strategy, innovation and accountability in public administration", a more extensive course that has been split into the two MOOCs mentioned. This course was first taught in person, through the Lifelong Learning Center of the UPV, and, later, it went online through the MOOC platform (EDx). The course had an estimated dedication of 40 hours spread over 10 weeks and there were two editions.

Initially, 386 students were enrolled, of whom 27 requested a certificate (having the same number of surveys and, being anonymous, we understand that these were the ones who filled them out). However, of these 27 students, only 21 managed to complete it (that is, 5.4% of the total enrolled). Their general degree of satisfaction can be considered high (16 students rated it 9 and 11 students rated it 8.2, out of 10). Of the 22 countries represented, the majority of students were from Spain, Mexico and the United States.

A first analysis of the surveys collected from these previous editions makes us think that a lack of initial motivation or interest, boredom, an excessive level of the course, inadequate content, too high learning rate, a bad platform design or technological barriers were not factors that promoted dropout, but rather the opposite, and only the student's lack of time was explicitly identified as a dropout factor.

For this reason, in the current courses, this long course was separated into the two commented MOOCs, adding other contents, with 30 hours over 5 weeks each. In this way, shorter courses could give students more flexibility. Given its impact, the EDx platform provides a Professional Certificate to those who complete both courses. On the other hand, a group was created on LinkedIn so that students who wish could contact with the participants of any edition and with the teachers.

However, given that the specific questions of the course that are asked from the UPV and the EDx platform, without including those specific to the platform, do not cover all the possible casuistry that we were interested in regarding satisfaction and dropout, we have developed, from the literature, two other surveys that complement these, one for the beginning of the course and another for the end. The courses were taught in the last quarter of 2022, and the information was collected at the beginning and at the end. On the other hand, the UPV also launched its own survey at the end of the courses.

4. FINDINGS

UPV surveys

In the last edition, 373 students were enrolled between the two courses, but still few students answer the surveys, therefore we have taken into account those students who have obtained the certificate and have completed the course (this is a number that we control better). If we look at the two courses, the number of students who have completed them out of the total enrolled has been slightly higher (9.1%), with 34 obtaining the certificate

(22 students from the first course, out of 27 who had initially requested a certificate, and 12 students of the second, of 16 who initially requested it). Besides, 11 of them have completed both, which curiously is practically the same number of students who have completed this survey (12). Satisfaction has been between 7.3 and 9.6, which is similar to the previous course. With regard to the duration of the courses, in this case the majority found it adequate, although one of them could not finish it.

Own surveys

In these surveys, there has also been a low number of surveys: 14 students have answered the initial and 9 students the final. In this case, the majority of students who filled out the initial survey had not requested a certificate, while in the final survey we found that the majority had requested it or had taken one of the courses at the suggestion of the teachers of the subject "Strategic Management of Public Organizations" (from the Faculty Bachelor "Public Management and Administration"). The initial survey shows highly motivated students, both for the topic and for the possibility of taking online courses. Most of them are Latin American. Therefore, it will be necessary to investigate more about the reasons why many of them did not finish it.

In the subsequent survey, satisfaction has been very high and the great quality of the courses above average stands out. In this case, the prior knowledge of some of the participants on the subject was superior. But it is interesting to insist that greater interaction is missing, since when something has been discussed in the forum the level has been high. For example, improvements are proposed such as:

> *"I suggest that there is someone who gives feedback to our participation in the forum, because that greatly enriches learning" or "There was little interaction with students and teachers, I suppose due to the dates prior to the start of the academic year."*

5. PRACTICAL IMPLICATIONS

The results are in line with the works that deal with the lack of interaction (Arias et al., 2019; Rosé et al., 2014; Yang et al., 2014; Jordan, 2015). Given the low number of responses to the surveys, we cannot say that they are representative of the entire group, however they allow us to draw different conclusions:

- It is necessary a greater knowledge about the reasons that lead students to abandon the course. Observing that surveys do not seem to be the best instrument, it would be necessary to have more direct contact with some randomly selected students or to carry out some type of participatory activity in the middle of the course.
- Greater interaction with teachers is required, either through the forums or the group created on LinkedIn.

- In this course, the students of the subject "Strategic Management of Public Organizations", to whom the Faculty had exempted from attending class for work or other reasons, were allowed to take one of the courses as a substitute work for 30 % of the evaluation of the subject. For the next academic year, since those who chose it were very satisfied, this possibility will become mandatory for exempt students.
- The platform estimates the dedication to the course between 4-5 hours a week, while the students who finished them dedicated between 2-3 hours. Perhaps it would be more realistic to announce this on the platform.
- Finally, taking into account that most of the students in the "Strategy" course are from Mexico and in the "Policies" course are from Peru, perhaps we could add some cases that focus on these countries.

6. FUTURE RESEARCH AND LIMITATIONS

With the first modification made, dividing a long course into two shorter courses, the completion rate has been slightly increased and the dropout rate decreased, in addition to achieving a greater response to the surveys, although it is still low. For the next courses, with the proposed developments, we hope to improve the figures again and reassess student satisfaction.

7. VALUE OF THE PAPER

In these MOOCs a greater motivation and involvement of the student is necessary through communication, interaction and direct feedback with the teacher, and among the students themselves (Garcia-Ortega et al., 2021; Woo & Reeves, 2007; Bonk and Graham, 2012; Galan-Cubillo et al., 2021), both on the course platform and through social networks (Moore and Fetzner, 2009).

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AUTHOR CONTRIBUTIONS

M. de Miguel: Conceptualization, Original draft & Supervision; M. Segarra: Review & Editing; G. Ribes: Investigation; R. Perelló: Validation; A. Peiró: Methodology; B. de Miguel: Formal analysis; D. Catalá Pérez: Literature & Data curation.

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SHORT ABSTRACTS

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SUPPORTING INNOVATION IN THE INDUSTRIAL DESIGN SECTOR THROUGH THE LEAN STARTUP METHODOLOGY AND ENSURING THAT ALL DESIGNERS UNDERSTAND ITS POTENTIAL IMPACT AND BENEFITS FOR THE CIRCULAR ECONOMY PROCESS

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ABSTRACT: The Lean Startup methodology has been a benchmark for start-ups for years. Its relation and application to industrial design is interesting for those designers/entrepreneurs who want to develop a product or service prototype knowing the implications it will have in a real market. The aim of this research is to highlight the importance of knowledge of this methodology in the field of industrial design in order to reduce actions, procedures, and materials before launching a new product and service on the market. The methodology of this study is based on the analysis of how startups related to industrial design have used the Lean Startup methodology as a design and innovation strategy, and its involvement with the circular economy. In this sense, the aim is to study and analyse whether the results show how the application of this methodology in industrial design represents an advance so that the products/services created follow part of the circular economy philosophy during the design process. In essence, the circularity of the process constitutes the basis of both models—Circular Economy and Lean Startup. It is therefore intended that this research would lead to a better understanding of whether industrial designers may integrate both techniques, viewing them as a single model, which would have a positive impact on the community of designers and, consequently, on society.

KEY WORDS: *Industrial design; lean startup; innovation; startups; management.*

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ORGANIZATIONAL COMPLEXITY AND INTERNATIONAL BUSINESS ENVIRONMENT

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ABSTRACT: Organizational Complexity plays an increasingly important role in organizations and can be considered one of today's most significant management challenges. This research analyses the role of complexity, its antecedents, and its impact in a highly dynamic and volatile business environment. Therefore, the main purpose of this paper is to highlight the importance of the concept of organizational complexity for organizations in connection with the international business environment. This research is based on a review of the topical literature to qualitatively summarize and put together in a logical flow the evidence on complexity, and to understand how this phenomenon can create uncertain external and internal environments for the organizations, and how by developing a new way of thinking can facilitate them to deal with complexity successfully. Findings indicate that the organizations operating in international business settings are highly affected by organizational complexity due to their complex structure, and a constantly changing environment with continuously new managerial and organizational requirements. Findings further indicate that complexity is perceived as a characteristic of an organization's structure that can be measured and described by the numerosity, variety, and interrelation of its constituent elements (Fioretti & Visser, 2004), for dealing with complex behaviour. The research concludes by emphasising that organizational complexity is essential for organizations and that it is crucial for them to understand the phenomenon of organizational complexity in order to survive and remain competitive in the global marketplace.

KEY WORDS: *Organizational complexity; complexity theory; complexity theory in MNCs.*

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ON THE TRAIL OF A MYTH: CREATING TRANSPARENCY ABOUT THE ORIGIN OF THE SHARED SERVICE CENTER (SSC) IDEA BY CONDUCTING A BIBLIOMETRIC SCOPING REVIEW

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ABSTRACT: Over the last four decades the idea of Shared Service Centers (SSC) has become a dominant solution to reorganize the internal service delivery of companies worldwide. The bundling of decentralized activities in a semi-autonomous unit promises various benefits. Cost savings, improvements in service quality and the push of digital transformation have caught management's attention and resulted in an SSC implementation rate of around 90% among Fortune 500 companies. Scientific work has accompanied this success story and tried to better understand its characteristics, implementation motives and associated levers for success. Despite numerous academic contributions, the entire evolutionary history of the SSC is undocumented, limiting conclusions about the scientific basis of this revolution. Therefore, the objectives of this work are two-fold: First, a scoping review strives for a comprehensive inventory of the SSC literature across all common citation, metadata, and publisher databases for economic research since the beginning of recoding (15 sources in total). Findings will be consolidated in a bibliometric analysis previously unavailable for this research area. Second, a decades-long reconstruction of citation chains around characteristics, benefits and success factors in the SSC implementation creates transparency about the scientific origin of such arguments, including their applied research methods. In summary, the paper aims to contribute to a holistic understanding of the SSC idea in a historical and methodological context. Acquired insights will support management in making implementation decisions between complex SSC designs and other less prominently discussed service delivery approaches.

KEY WORDS: *Shared Services; SSC; Shared Service Center; Scoping review; Bibliometric analysis.*

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CONFLICT OF INTERESTS

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THREE-FOLD INNOVATION STRATEGY AS A DRIVER OF SUSTAINABILITY IN TOURISM

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ABSTRACT: Companies in the tourism sector are currently facing two major challenges: technological progress and sustainability. To cope with both, companies have relied on economic motivations as the driver for compliance, leaving the social and environmental areas unaddressed when it comes to connecting both and when learning about the virtues of meeting them simultaneously. Therefore, the main objective of this paper is to find out whether innovation can favour the pursuit of sustainable objectives by tourism companies. Specifically, the aim is to find out whether there are differences in the influence of different types of innovation (social, economic, and environmental) on the relationship between sustainability and performance. To meet these objectives, an empirical analysis of a sample of 202 tourist accommodations on the Spanish coast, especially hotels, is carried out using the Partial Least Squares technique (PLS-SEM). Useful results are obtained regarding the relationship between sustainability and performance as well as the influence of different typologies of innovation on this relationship, analysing their mediating effect. Specifically, it provides valid conclusions that will enable both academics and hotel managers to focus their attention on developing the right type of innovations to make the pursuit of sustainability and technological development congruent and compatible in the business strategy.

KEY WORDS: *Sustainability; Innovation; Tourism; Performance.*

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EXAMINING THE FASHION RETAILER´S STRATEGIES TOWARD SUFFICIENT CONSUMPTION

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ABSTRACT: This paper investigates whether five of the world's leading fashion retailers are adopting strategies to promote sufficient consumption and fight consumerism, considering its negative impact on the environment. A theoretical framework for promoting sufficient consumption collected from the existing literature is presented, outlining the strategies or initiatives that fashion companies may adopt for this purpose. To investigate the adoption of these strategies, a qualitative analysis of the annual and sustainability reports issued by these companies during the period 2020-2022 is conducted through direct reading. The findings suggest that although these companies make efforts to project an image of social responsibility and sustainability, they are not yet actively implementing strategies towards sufficient consumption, and rather continue to promote consumerism. This study highlights the need for further efforts to encourage the adoption of a sufficiency approach by companies in the fashion retail segment toward more sustainable business models, with the support of stakeholders such as consumers and policymakers.

KEY WORDS: *Fashion retailers; sufficient consumption; consumerism; sustainability; business models.*

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GOOD START AND SAFE LANDING - DRONES AT THE UNIVERSITY

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ABSTRACT: The technological development of commercial drone systems has progressed rapidly over the past ten years. Their application in a wide variety of professional work areas is becoming increasingly important. This paper presents various civilian-only applications of UAVs (unmanned aerial vehicles) and examines how university graduates can be adequately prepared for these new scientific and practical requirements. A special focus is on the "Bavarian Drone Academy". This interdisciplinary facility was founded in 2019 at the Ansbach University of Applied Sciences. The Drone Academy provides the opportunity for every student to exercise the professional use of drones in an application-oriented and practical way. The academy's portfolio currently includes the following modules:

- Legal and technical requirements of UAV
- Photography and videography with drones
- Thermography with drones
- Aerial photography and photogrammetric methods
- Practical exercises and flight training with drones.

According to the current EU Drone Regulation 2019/947, most professional operations require the acquisition of a remote pilot license (A2) for drones. The drone academy has received a permit from the federal aviation authority (LBA) to act as an A2 examination centre. This enables our university students to get the pilot's license as part of the curriculum.

This presentation reports on initial experiences with this course program. In addition, some current research projects that the Drone Academy is working on are presented.

KEY WORDS: *Technology education; unmanned aerial vehicles; civil drone applications.*

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AUTOMATIC DETECTION, CLASSIFICATION AND LOCALIZATION OF AGRICULTURAL OPERATION AROUND WIND ENERGY PARKS

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ABSTRACT: To operate a wind park in accordance with regulations of the European Union with respect to animal and environmental protection, especially the protection of endangered birds and bats, all wind turbines have to be shut off during times of highest activity in and around the wind park. Conventionally, the farmers have to manually communicate these operations to the operator of the wind park, who has to quickly trigger the appropriate response, e.g. stopping the blades for a predetermined number of hours. The manual procedure has multiple points of failure, which may hinder the protection of the animals, the operation of the wind farm in accordance with legal regulations or the efficiency of the power generation. We present a solution using Convolutional Neural Networks to detect the different operations of farmers in and around wind parks. The solution extends an operational prototype. Similar to the famous family of YOLO networks, we perform classification and bounding box regression at the same time. We compare the performance of adapting a pretrained network to multiple networks trained from scratch on the task with different optimization strategies. Preliminary results indicate that we are indeed able to identify more types of scenarios in the images than the prototype, and that the localization of the operation is more reliable with pretrained networks.

KEY WORDS: *Artificial intelligence; computer vision; wind energy; renewable energy.*

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Madrian, Fynn: Data curation; Formal analysis; Investigation; Software; Visualization. Geißelsöder, Stefan: Funding acquisition; Resources; Supervision; Validation; Roles/ Writing - original draft; Writing - review & editing.

All: Conceptualization; Methodology; Project administration.

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DETECTION OF ALLERGENS IN PRODUCT INFORMATION USING COMPUTER VISION

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ABSTRACT: This work demonstrates the application of Computer Vision techniques such as deep neural networks and optical character recognition (OCR) on product information of food packaging. It helps to recognize various personalized allergens, for example for people with lactose intolerance or gluten intolerance. The aim of the research is to make life easier for those affected and to help them identifying potentially allergenic foods faster. We collected a data set of images of food packaging, which contain different common types of allergens and their declarations. The outcome of several preprocessing steps on these images serves as the basis for the development of a model that is able to recognize and extract important parts of the packaging. Subsequently a text analysis is used to check the contents of extracted texts for the presence of allergens such as lactose or gluten and other associated contents. We use rule-based approaches as well as machine learning to increase the accuracy in the detection and classification of allergens. With the devised system, field tests are carried out under real-world conditions to verify the practical applicability of the system. The current state of the project can clearly recognize relevant keywords, and we focus our further research to enhance the reliability of the detection. This research can therefore contribute to improve the quality of life of people with various allergies by providing them with a helpful and fast tool in order to be able to protect themselves from harm when shopping for food.

KEY WORDS: *Artificial Intelligence; Computer Vision; Consumer Protection.*

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Uhl, Maria and Knoke, Vivian: Conceptualization; Data curation; Formal analysis; Investigation; Software; Visualization; Roles/Writing - original draft. Geißelsöder, Stefan: Funding acquisition; Resources; Supervision; Writing - review & editing.

All: Methodology; Project administration; Validation.

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HARDWARE SETUP FOR A FUTURE AUTONOMOUS MOBILE MANIPULATION ROBOT SUITED FOR SMALL MATERIAL HANDLING

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ABSTRACT: Autonomous Mobile Manipulation Robots (AMMR) are becoming an growing part of research in applied artificial intelligence as well as visions of future every-day life due to their ability to handle complex tasks independently and to support humans. It is mandatory do define the requirements on an AMMR application and to use suited hardware. For an AMMR capable of handling small materials on the one hand a mobile platform is needed and on the other hand some kind of manipulator must be used. Our studies showed that, for the given use case, the Leo Rover platform fits because of the project ready development status as well as the options for flexible extensions. Furthermore, it utilizes a versatile Raspberry Pi 4B as its main computer and a capable power supply for additional hardware. A WindowX 250 manipulator is attached on top of the rover with a customized 3D-printed adapter and enables manipulations of its environments. Upgrades of multiple sensor devices are indispensable to enable upcoming autonomous operation. We added two 3D cameras, Luxonis OAK-D in front of the mobile base and Orbbec Astra Stereo S on the manipulator's elbow, to enhance mapping and location capabilities as well as more precise grasping manoeuvres. Around the Rovers base eight ultrasonic sensors, controlled through an additional Raspberry Pi pico are mounted to add to the reliability of the other sensors' measurements. The distance to obstacles measured by these ultrasonic sensors is also signalled by a traffic light system combined with a buzzer. We investigate the capabilities and shortcomings of this setup with respect to the planned autonomous operation.

KEY WORDS: *Robot; AMMR; manipulation; autonomous.*

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AUTHOR CONTRIBUTIONS

Vahlensieck, John: Data curation; Formal analysis; Investigation; Methodology; Software; Visualization; Roles/Writing - original draft. Geißelsöder, Stefan: Funding acquisition; Resources; Supervision; Writing - review & editing.

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DIGITAL MARKETING STRATEGIES AND PROGRAMS IN TENNIS CLUBS: THE VIEWS OF THEIR GENERAL MANAGERS

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ABSTRACT: The purpose of this paper was to explore the digital marketing strategies and programs in a sample of tennis clubs. Digital marketing research in tennis has mostly focused on organizations such as federations or professional tournaments and on players or coaches. Even though there are more than 70,000 tennis clubs worldwide and that they are considered the backbone of tennis development, researchers have shown little interest on the digital marketing strategies implemented by these organizations. It was hypothesized that the strategies and programs delivered would depend on factors related to the clubs' budget, membership, number of employees and marketing strategy. The sample consisted of a cohort of general managers (n=10) of selected tennis clubs who participated in individual semi-structured interviews which were analyzed and classified thematically following a qualitative methodology. The results showed that clubs with larger budgets, more staff and members, and a more targeted marketing strategy tended to implement more ambitious, regular, varied, and individualized digital marketing strategies and programs than those that were not. The findings of this study led to the conclusion that the digital marketing strategies and programs of tennis clubs are clearly influenced by the specific characteristics of the tennis club ecosystems. This research also has clear practical implications as it allows sharing examples of good practices that can be applied to all sports clubs as well as the production of informative and educational resources for managers and people responsible for this business area of these organizations.

KEY WORDS: *Racket sports; technology; communication; innovation; business.*

CONFLICT OF INTERESTS

The author declares that he does not have any conflict of interest and that he did not receive any funding to conduct the research.

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GETTING ON BOARD VIRTUALLY – A MODEL OF ORGANIZATIONAL SOCIALIZATION IN THE NEW NORMAL

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ABSTRACT: This conceptual article moves the conversation about virtual organizational socialization forward by combining knowledge about virtual work and organizational socialization. In contrast to past research on organizational socialization, which viewed virtuality and the use of technology negatively concerning newcomer adjustment, we lean on the virtuality-as-paradox perspective. This means that virtuality has negative and positive effects that may outweigh one another. Recently, researchers have called for focusing on how virtual work can be successfully performed rather than asking whether virtuality at the workplace is good or bad. The trend of working remotely definitely endures in the new normal established after the covid-19 pandemic. Based on a review of the literature in the field of virtual teams, remote work, and computer-mediated work, we develop a model of virtual organizational socialization, considering the role of leadership, task dependency, social learning, and trust. We concentrate on recent literature, taking into account the opportunities new technologies and collaboration tools offer, in contrast to the focus on e-mails and videoconferencing that dominated past research. The practical implications of this model — especially what organizations can do to improve the organizational socialization of newcomers who work remotely — are discussed.

KEY WORDS: *Organizational socialization; virtual organizational socialization; virtual teams; remote work; leadership.*

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Business Meets Technology
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Daniel Catalá Pérez, M Rosario Perello-Marín, Conrado Carrascosa López (Eds.)

The **5th International Conference "Business meets Technology"** took place on July 13th to 15th at the **Universitat Politècnica de València** (UPV), Spain.

The **4th International Conference "Business meets Technology"** took place from 7th to 9th July at the **University of Applied Sciences of Ansbach**, Germany.

The **3rd International Conference "Business meets Technology"** took place on September 23rd and 24th 2021 in the Business Organization Department with the support of the Faculty of Business Administration and Management of the **Universitat Politècnica de València** (UPV), Spain.

The **first** and **second edition** of the Conference were held at the **University of Applied Sciences of Ansbach**, Germany, in 2018 and 2020, respectively.

The theme of the conference was «Business Meets Technology». By suggesting such a broad topic, we aimed to invite researchers with a variety of interests in theory and research in various areas of science, commerce and arts related to business and technology. By providing a general motto, we emphasized that contributions from all areas of science are welcome.

The objective of the event from its multidisciplinary approach was to allow generating and contributing valuable knowledge to face the great social challenges established as political priorities by the programs European science, research and innovation framework.

The international focus of the event, with the participation of leading experts from European universities, both in the scientific committee and in the scientific program as invited speakers, enriched the exchange of knowledge for all attendees.

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