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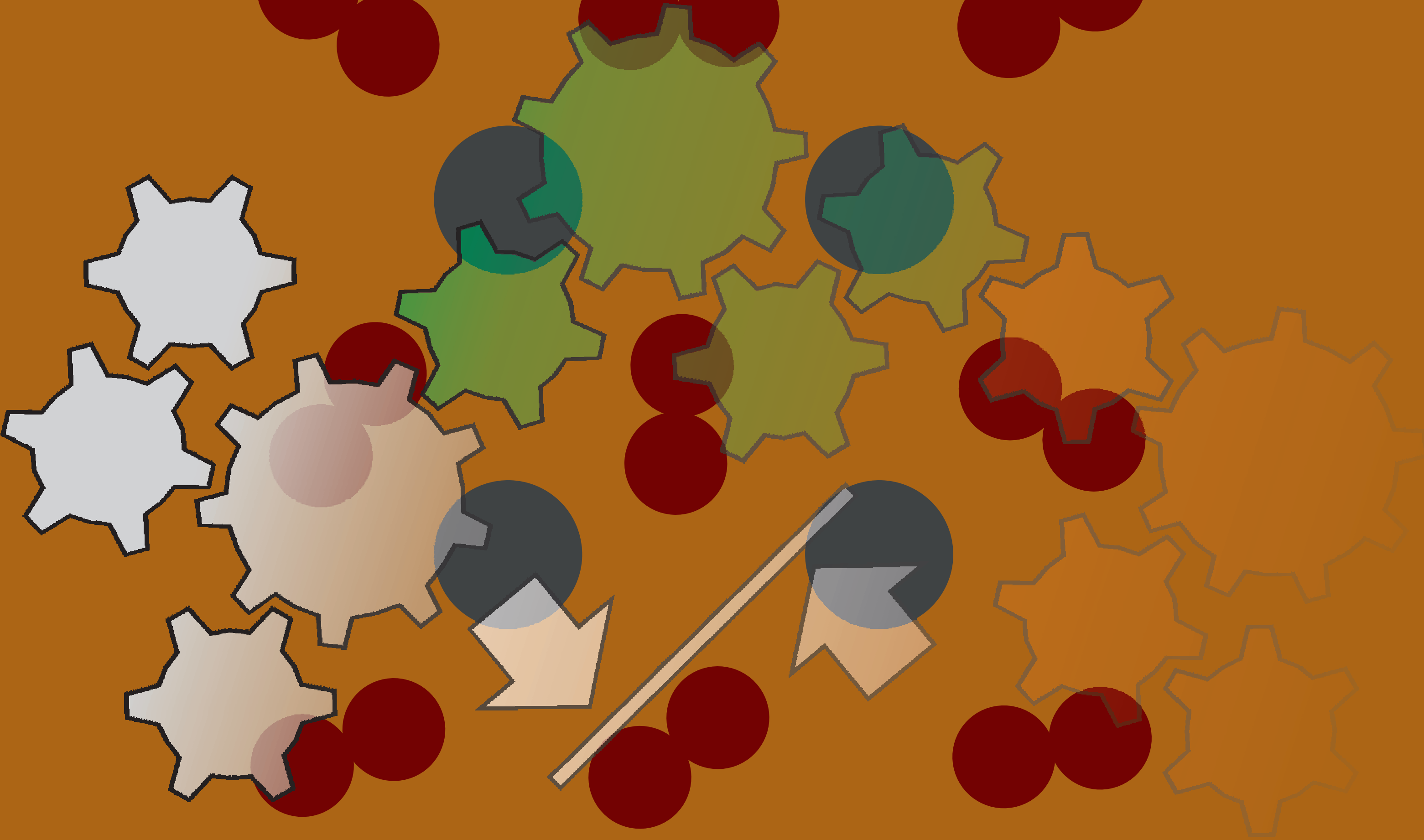

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Technological process of design and production of facial burn mask

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Keywords: skin burns, facial mask, facial orthosis, 3D printing, 3D scanning.
Abstract: This article deals with the issue of the management of facial burn treatment using an orthotic device. Discusses the possibilities of using thermoplastic as a suitable material for the production of facial orthosis. It describes the methods of obtaining measurement data of the patient and the subsequent design and production of the orthotic aid using traditional and innovative methods. Subsequently, a model of the human face was obtained using the Artec Eva optical hand-held 3D scanner, which served as a basis for the design of the facial mask in the Meshmixer software. From the conclusions, it is clear that the process of manufacturing a burn mask using innovative methods brings many advantages, in terms of patient comfort and time-saving, compared to conventionally used procedures. After verifying this methodology and verifying the biocompatibility of the proposed material, it would be appropriate to put the methodology proposal into practice.

1 Introduction

Burns are one of the most common injuries in all age groups. Globally, according to the World Health Organization (WHO), approximately 180,000 people die from burns each year. They are mostly people from low to middle-income countries, where, statistically, the most burn victims are. Of this number, up to two-thirds are from Africa and the regions of Southeast Asia. This is also related to a higher level of education in the field of burns and knowledge of providing first aid in more developed countries, where the number of burn victims decreases every year thanks to the rapid development of medical facilities [1].

Scars are the long-term complication of burns to the face, head, neck, and other areas. Over time, these can significantly limit the mobility of some parts of the patient's body. The formation of a scar is associated with a contraction, which leads to a disturbance of the movement properties, especially of the lips (microstomia), or the eyelids. When such a scar occurs, the only option to restore the functionality of the tissue is to cut out the scar, which, however, creates a defect on the face. Therefore, the optimal solution is to eliminate the risk of these scars in the healing phase of the damaged tissue [2].

Hypertrophic and keloid scars are caused by deep burns, which we classify between the second and third degree. These scars need to be treated appropriately and taken care of so that they are as aesthetically and functionally acceptable for the patient as much as possible. In general, the deeper the burn and the longer the healing time, the more prone the damaged tissue is to excessive growth - hypertrophy. The scar does not become hypertrophic immediately after the healing of the burned area, but only during the first 3-6 months after the burn. After this time, hypertrophic scars tend to regress, meaning they flatten, soften, and become lighter in color and more elastic. The risk of developing a hypertrophic scar is higher in children and adolescents than in adults [2].

During the first to sixth month of healing, hypertrophic scars are pink, red, or purple, and their surface is raised. They are dry, tend to itch, and are sometimes even painful. Their structure is rigid, brittle, inflexible, and without elasticity. Stripes tend to form on their surface. Scars themselves deform, but they also deform the undamaged tissue around the scar. With more serious deformations, limited movement of the joints may also occur. Sometimes small blisters with clear contents or with blood form on the surface of the scar.

This can occur with mechanical damage to the scar or when the ducts of the sweat and sebaceous glands located under the scar are blocked [3].

In the period of one to three years after the burn, the scar becomes more flexible and pliable, which means that it is possible to shape it with different procedures.

In some cases, patients are forced to undergo reconstructive plastic surgery, where the damaged area is cut out. As far as non-invasive procedures are concerned, it is also customary to apply lubricate the scarred area, pressure massages, or splints [3].

Some scars tend to exceed the size of the original scar, which are keloid scars. These scars are coloured purple, are significantly raised, and do not tend to regress. The treatment of these types of scars is therefore much more difficult than the treatment of hypertrophic scars. Freshly formed scars must be protected from mechanical and chemical damage and adverse physical influences [2,3].

The goal of the research is to introduce the design of additively manufactured orthotic aids that are used for the treatment of burns, specifically burn masks that are made of transparent thermoplastic, individually based on a 3D scan (or cast) of the part of the patient's body.

2 Methodology

Burn treatment can be divided into the following categories:

- Medicinal treatment – cooling gels, topical ointments, pain relievers,
- Treatment using medical material – hydrophilic, gauze, elastic, biosynthetic, or pure cotton bandages, silicone patches,
- Treatment using an orthotic device – textile or plastic face mask,
- Skin transplantation – skin replacement with a skin graft,
- Implantation of biomaterials – e.g. Integra [4,5].

When treated with an orthotic device, these are orthoses that speed up the tissue healing process for patients after suffering a burn and also allow doctors to monitor the healing process without the patients having to take off the mask. They also serve as prevention against the formation of hypertrophic and keloid scars.

Currently, the conventional method of producing burn masks is by casting and then molding thermoplastic material over a patient model, which creates a replica of the contours of the patient's face.

2.1 Materials used for facial burn mask production

Choosing the right material is one of the most important parts of the medical device manufacturing process. Polymers in particular have many properties that can be used for medical applications. They are divided into three groups - thermoplastics, thermosets, and elastomers [6]. The most advantageous material for the production of a burn mask is a transparent thermoplastic. The advantage of thermoplastics is the possibility of producing the aid using additive manufacturing technology [7].

Also, its transparency ensures trouble-free monitoring of the condition of the damaged part of the body, without having to remove the device from the patient. Thermoplastics, which will be used as production material for facial masks, must be well tolerated by the human body. This factor is especially important from the point of view of higher susceptibility to infection after a burn. Among the thermoplastics that can be used for the production of facial masks are e.g. PLA (Polylactic acid), PP (Polypropylene), PE (Polyethylene), and PCL (Polycaprolactone).

Burn masks can also be made from thicker fabrics. These masks also apply pressure, but it is not possible to monitor the condition of the burn through them. However, these textile masks provide better breathability than thermoplastic masks. One of the usable textile materials is, for example, Sohatex. It is a highly elastic black material. It has a special spatial structure that ensures the skin's breathability. Its fibers help to keep the skin dry by transporting moisture away from the skin. For example, the use of elastic knitwear is also suitable, because this material can provide suitable circular compression [8].

Silon-STS (STS – Silicone Thermoplastic Splinting) is another optimal material for the production of facial burn masks. It is a product that combines the good formability of thermoplastic and the healing effects of silicone coating. It is a thermoplastic burn mask that is lined with silicone on the inside. The silicone sheets are used to treat scars. They act as a barrier against external, harmful influences. Silicone can mimic human skin and retain moisture in the body. It also prevents itching and redness of the skin during treatment. The silicone-lined burn mask also provides spot heating to adjust mask pressure [9].

2.2 Facial burn masks

There are also mass-produced orthotic aids for the treatment of burns – textile burn masks. However, they are less practical, as they are produced in only a few sizes and it is also not possible to monitor the condition of the skin through them.

HealthPartners (Minnesota, U.S.A.) offer a custom-made translucent face mask. This mask acts on the tissue with a slight pressure, which prevents the hypertrophy of the scars. Compression of the mask is achieved by strapping it to the back of the patient's head and securing it enough to exert slight pressure on the damaged tissue. The effectiveness of this facial mask depends on two factors: good coverage of the facial surface (the mask should follow all the folds and contours of the face) and adequate application of pressure on the scars. A big advantage of this facial mask is its transparency, thanks to which the doctor can monitor the compression areas of the mask for scars and modify the mask accordingly [10].

Scheck & Siress Prosthetics (Chicago, U.S.A.) also produce similar facial mask.

The plastic burn mask from this company has a layer of silicone applied on the inside for patient comfort and for the beneficial effects of silicone on wound healing. Jobskin (Nottingham, United Kingdom) also uses plastic facial mask to speed up the healing process after burns and to prevent the formation of keloid scars. Masks are made from high-temperature thermoplastic, which is covered with a layer of silicone. This combines the beneficial effect of silicone and the effect of moderate pressure by mask [11].

According to some studies, masks can be used after skin graft transplantation, or they can also be applied directly to the burned tissue if it is capable of regeneration [12]. Mass-produced burn masks include textile antimicrobial compression masks that use a pressure of approximately 15 to 25 mmHg to reduce capillary flow. This type of mask is globally one of the most widely used aids for regeneration after facial burns. Textile masks are produced in series, they are mostly available in sizes S, M, L, XL [13].

2.3 Obtaining measurement data

To design a burn mask, it is necessary to obtain the dimensions of the entire facial part of the subject´s head. The model should accurately copy the contours of the face region and also capture detailed areas such as folds around the nose, chin, and supraorbital arches, as the goal of this mask is to make the patient's face as close as possible to its original state before the burn.

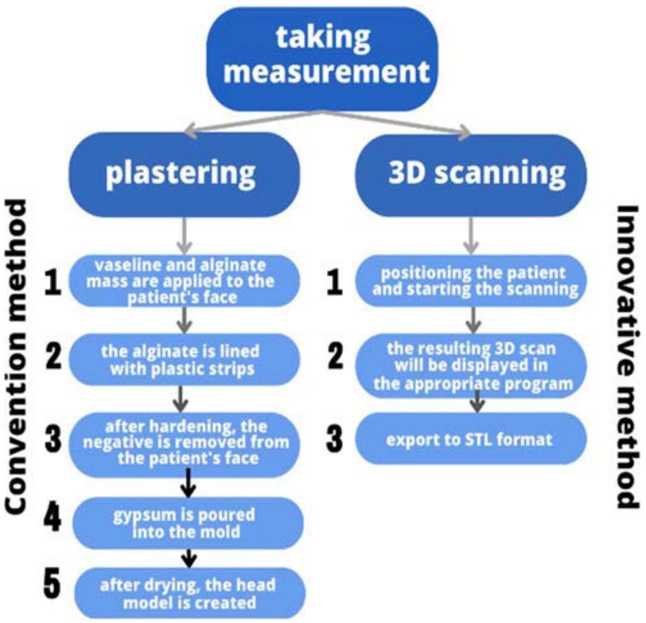

Figure 1 Methods of taking measurements for the production of a burn mask

2.3.1 Conventional method of acquiring measurement data

This traditional method consists in covering the wounds with plaster, which is time consuming and physically exhausting for the health worker and painful and uncomfortable for the burn patient. Sometimes it is necessary to give anesthesia to the patient during this process. This method produces a lot of waste and often injures the health worker [14].

The advantage of acquiring measurement data with traditional plastering is mainly the low price and the requirements for only basic equipment. There is also no need for special training of health workers. With such plastering, the health worker can influence the patient's soft tissues with his strength and thus get a more accurate model. This is especially useful in the hair area, whereby by pressing the hair to the head, a more detailed model of the skull can be obtained. However, in some cases, the action of the health worker's power can lead to the deformation of the tissue, which will give distorted results. This occurs especially in cases where measurements are taken in places with soft, pliable tissue [14].

The procedure consists in applying an alginate mass, which hardens over time and serves as a mold for making a cast on the patient's face [10,15].

2.3.2 Innovative method of acquiring measurement data

The manual 3D scanning process offers several advantages over traditional contact measurement. This method is completely painless for the patient, non-invasive, and there is no risk of transferring bacteria, as there is no contact with the patient's burned face. In addition, this method is also very fast, physically easy, and clean for an experienced worker. The resulting 3D scan of the patient's face provides detailed contours of the face, which is not always possible to obtain with a plaster cast.

The main disadvantage of 3D manual scanning is the higher price of this device [16].

2.4 Production technologies

There are several ways of produce the facial burn mask itself. When choosing a suitable production technology, the material from which the mask is being made, is mainly taken into account.

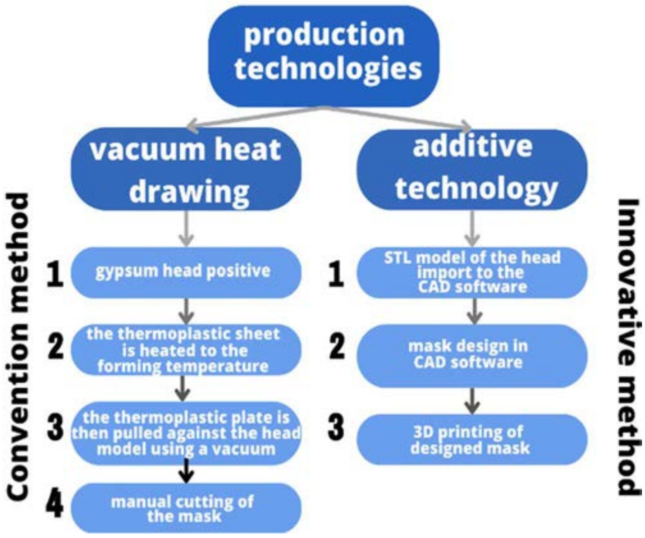

Figure 2 Burn mask production technologies

2.4.1 Conventional method of burn mask production

This method involves vacuum forming or deep drawing of thermoplastics. Vacuum forming is one version of thermoforming. The principle is that the thermoplastic sheet is heated to the forming temperature. It is placed in the device together with a mold model of the facial part of the subject's head. The heated thermoplastic is then pressed against the model using a vacuum. One of the disadvantages of this molding method is the occasional formation of bubbles on the inside of the plastic, which reduces the quality of the product. There is also a risk of overheating the material, which results in the formation of bands around the mold [17].

Another variant of mask production by drawing is a deep drawing of thermoplastics using a vacuum. In this case, the processed plaster model is placed on a stretching ring with a vacuum outlet. The thermoplastic is attached to the stretching hoop and can be heated in the oven. After heating, the thermoplastic hoop is stretched to the positive. It is necessary to focus on the even distribution of forces in the hands. After hardening and cooling, the facial mask is removed from the positive and sanded [18].

2.4.2 Innovative method of burn mask production

The advantage of using innovative methods such as additive manufacturing (3D printing) is the production of the mask exactly according to the digital design with high surface accuracy, the application of special shapes and patterns, normally complicated or impossible to produce by conventional methods, and rapid production. Additive manufacturing of the mask significantly reduces the amount of time and also the material, which would be otherwise used to make a model of the face mask or would be cut off during the final shaping of the mask into the desired shape.

This entire process is eliminated when using additive manufacturing technology for burn mask production.

Another advantage is that there is no need to cut holes for the eyes, mouth, and nose in the mask, as they can be designed directly in the software. It is also possible to print the device with a porous structure to prevent sweating and other skin problems caused by insufficient ventilation.

The disadvantage is the initial high price of the device, either of the 3D printer itself or the material used, but it is more efficient from a time point of view, which means a reduction in the number of standard hours required for the production of the mask. In additive manufacturing, a certain amount of expertise is also important, which is not very common. Also, it is not possible to use all available materials in 3D printing that would be suitable for a burn orthotic device such as Silon-STS. While traditional silicone cannot be directly printed using conventional 3D printers, some alternative materials and techniques can replicate some of its properties, such as TPU (Thermoplastic Polyurethane), some soft resins or thermoplastic polymers with additives to achieve a similar level of flexibility and softness.

The procedure is to first insert a 3D model of the subject´s head into the CAD (Computer Aided Design) software. The model will be adjusted and the orthotic aid will be designed directly in the software. It is separated from the head model in the software and can then be produced using the FDM (Fused Deposition Modeling), SLA (Stereolithography), or SLS (Selective Laser Sintering) technology. Material suitable for 3D printing of an orthotic device is, for example, PA (nylon), PU (polyurethane), or PLA [19].

2.5 *Facial burn mask design*

One of the proposals to simplify the design and production process of a facial burn mask starts with scanning the patient's face. After obtaining a 3D model of the head with an adequate 3D scanner, such as Artec Eva 3D scanner (Artec 3D, Luxembourg, Luxembourg), the mask was modelled in the appropriate CAD software Meshmixer (Autodesk, San Rafael, California, USA). First of all, it is important to mark the area of the face that the mask should cover. The mask should not extend below the supraorbital arch, as the compression applied to this area could cause pain for the patient. The mask covers the entire surface of the face, i.e. from the hairline to the bottom of the sledge, except the eyes, mouth, and nose. Lateral openings in the area of the sphenoid bone and under the cheekbone were modelled in the program for the placement of Velcro straps. After the exact marking of the surface, it is necessary to set the required thickness and smooth the corresponding edges. The thickness of the model was set to 1.8 mm. The standard range of mask thickness is between 1 and 3 mm, depending on the required level of stiffness or flexibility.

If necessary, the mask can be aligned with the original 3D scan of the face to verify the accuracy of the mask model. The resulting model is exported in STL (Standard

Triangle Language) format, which is suitable for additive manufacturing.

This method of designing a burn mask was relatively quick (less than 1 hour), with minimal subject involvement. The final quality of the actual mask depends on the selected material and the chosen additive manufacturing technology.

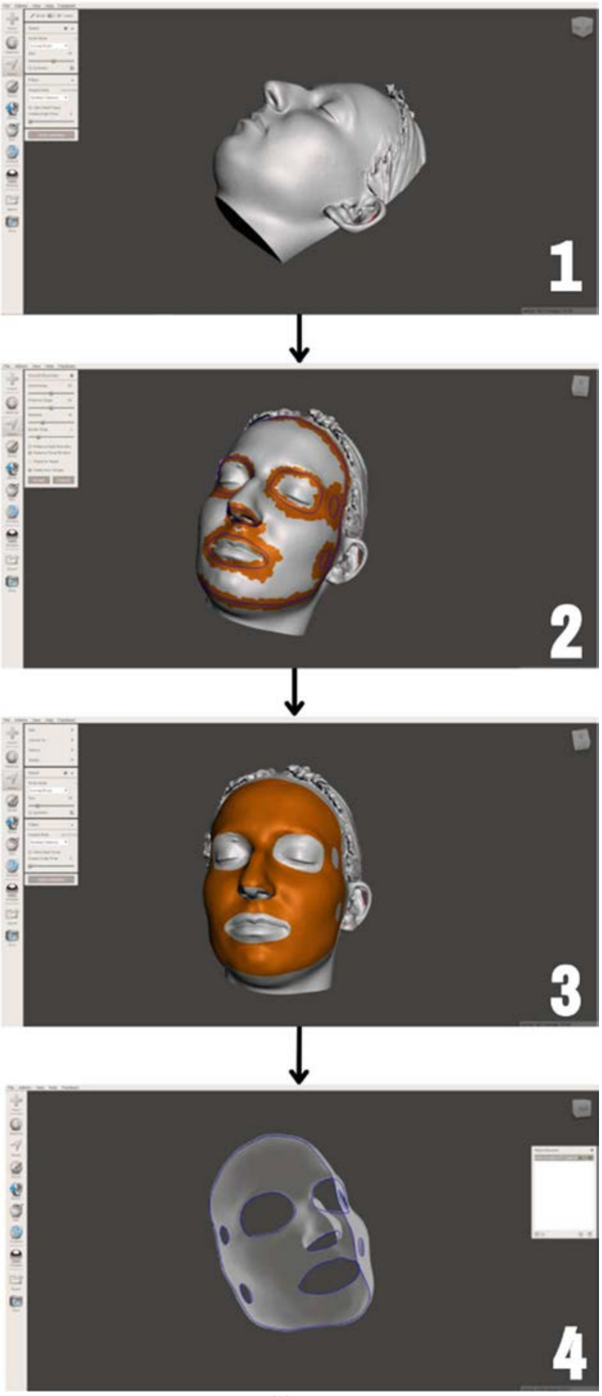

Figure 3 Illustration of facial mask modelling (Meshmixer software)

3 Discussion and conclusions

As part of the study, various methods of manufacturing a burn facial mask and also of taking the subject´s measurement data were presented. A conventional and innovative method of producing a burn mask was described. The conventional method of production has been used in the healthcare industry for many years, and therefore it is necessary to come up with a solution that would increase the comfort of the patient and make the work easier for the health workers. Based on this, the innovative possibilities that modern technologies offer us were highlighted.

By using a 3D scanner, measurement data were obtained for the design of the medical device. The freely available CAD software Meshmixer was used for editing 3D models and for the actual design of the burn mask. This innovative procedure allows the mask design that copies the topography of the subject´s face with high surface accuracy.

Additive manufacturing and 3D scanning greatly simplify the complicated process of manual burn mask production, with a great advantage, which is the non-contact and pain-free process for the patient. The mask model made using the described methodology is suitable for additive manufacturing. PA, PU, or PLA materials were selected as materials suitable for the production of this medical device. These materials are biocompatible and are used in orthotics development, but it is necessary to verify their suitability for burn wound treatment.

Future research will include the design and additive manufacturing of a mask for a specific patient with a facial burn. The research will also focus on material possibilities in orthotherapy for facial burn treatment.

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Personalized modification of sport dance wheelchairs

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Keywords: wheelchair, dance, sport, personalization.

Abstract: Standard modifications of active wheelchairs are commonly performed, but they often do not take into account the individual needs of dancers. The presented article aims to propose the optimization and personalization of the Quickie Argon Ti dance wheelchair for a specific subject. A visualization of a personalized dance wheelchair was created, abiding by the dimensional frame. The quality of the performance of physically disabled individuals in sports dancing on wheelchairs is significantly influenced by its construction and parameters. In this article, a standard sports wheelchair, and the requirements placed on a sports wheelchair used for dancing were described. After addressing the shortcomings, the modifications of selected components of the disabled sports wheelchair were presented.

1 Introduction

Wheelchair dancing is an activity that integrates a wheelchair user and a healthy dance partner. Wheelchair dancing was initially used for recreational and rehabilitation purposes. It was created in Sweden in 1968. Els - Britt Larsson, a wheelchair user who worked for the Swedish Federation for the Disabled, was one of the pioneers of the sport. Wheelchair dancing spread very quickly and became a popular sport, especially in Sweden.

In 1998, wheelchair dancing became an International Paralympic Committee (IPC) division but is not part of today's Paralympic program. It is under the organization of IPC and overseen by the Dance Technical Commission, which includes the rules of the World Dance Sports Federation (WDSF) [1].

Physical benefits of wheelchair dancing include maintaining body balance, flexibility, range of motion, coordination, and improved breathing. The psychological effect of dance is social interaction and the development of relationships. For beginners, it is an opportunity to join in a fun and friendly event with others. For advanced dancers, it helps in the development of the idea of “fair play”, sportsmanship and communication skills [1].

Wheelchair dancing is a defined type of dance. Standard dances are waltz, tango, Viennese waltz, slow fox and quickstep. Latin American dances include samba, cha-cha, rumba, paso doble and jive.

Sports wheelchairs differ from regular wheelchairs in terms of design and components that improve personal comfort and performance when engaging in physical activity. The frame is light for easy handling. The front wheels and the rear 5th or 6th wheel are of a similar type as used on roller skates. The 5th and 6th wheels are used to ensure stability and balance when manoeuvring. Depending on wheelchair setup, build and personal preference, the rear wheels range from 609.6 mm to 660.4 mm in diameter. They are also equipped with hoops and a footrest. The backrest can be adjusted to different heights depending on the level of functionality of the body. Those athletes who have an active upper body do not need a high backrest. They can sit higher than those who require more back support. The backrest reinforcement is adjustable as needed to provide the best possible back support. A suitable seat cushion is also important. Its size, thickness and shape can vary depending on the specific needs of each athlete [2].

2 Dancing wheelchair

The dance wheelchair is a joint combination of a basketball wheelchair and an active wheelchair [3]. Wheelchair basketball mixes brief, intensive exercise bursts of quick acceleration and deceleration, dynamic position adjustments, and maintaining or gaining one's place on the court [4]. The basketball sports wheelchair is the basic pillar for other sports wheelchairs. It is characterized by a large variability of the basic setting of the frame. This means that the center of gravity, height and inclination of the seat can be adjusted. The robust frame for

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basketball wheelchair ensures safety and prescribed dimensions. The wheelchair is suitable for recreational and pro sports. The advantage of the basketball wheelchair is the inclination of the wheels of 16 to 20 degrees, which enables optimal stability and maneuverability.

The active wheelchair is available in different widths, depths and heights from the ground, with an integrated or folding front part, with connected self-folding and split footrests, with mudguards and board sides, as well as with different types of backrest.

Figure 1 Qiciki Argon Ti [3](A) and Quickie Argon Ti with modification for dance sports (B)

The dance wheelchair was inspired by the basketball wheelchair compactness and simplicity of its structure, the possibility of adjustment, whether the center of gravity or the height of the seat, the inclination of the wheels, and used materials. Also, as there is no need for rear handrails and brakes (depends on the user's requirements), armrests are replaced by the protective side panels. These are not only protecting the user from rotating wheels but are also defining the seat. Such parts save a significant amount of weight. The current trend in the development of the dance wheelchair is a move towards an all-welded frame, which is easier to maintain. The center of gravity is located approximately at the axis of the seated person; however it depends on the dancing disposition and the requirements of the dancer. The closer the center of gravity is to the axis of the sitter, the more accurate rotations and better control the dance wheelchair is. A dance wheelchair means the same to a wheelchair user as legs to a healthy dance partner. The dance wheelchair in question, which is personalized, is based on the model of active wheelchair Quickie Argon Ti (Figure 1). Quickie Argon Ti modified for dance sports differs from the base model with a narrowed front frame, lowered backrest, compact front brakes, sport lightweight wheels and carbon sidewalls, luminous front wheels, and not included handles. Other modifications are the reduction of the inclination of the wheels from the original 9° to 6° and an adaptation by raising the seat to the level of the protective side panels. At the moment, the wheelchair is suitable with its settings, but changes within the modification could bring improvements in properties and weight reduction. It is used for both standard and Latin American dances in a combined couple.

2.1 Proposal for a modification of a sports wheelchair intended for dancing

Due to the possibility of a wide variety of modifications, there is a large number of screw connections. These need to be tightened more often when using the wheelchair for dancing. Loose screw connections are manifested on the wheelchair by "popping" sound. This means that the wheelchair emits the mentioned sound when crossing an unevenness or during a dynamic movement. The subsequent elimination of the problem is very time-consuming. Another disadvantage is the frame, which is fixed to the axle of the wheels via beams, and forms a mechanically stressed open system. The height of the backrest initially met the requirements. However, the development of dancing skills can cause the wheelchair user to be limited by it in dancing. The modifications of the dance wheelchair consist of replacing individual selected parts of the wheelchair with a stable, non-adjustable replacement and a modification of the frame into a mechanically stressed closed system. This achieved higher resistance and strength. Therefore, the problems with bolted joints were eliminated. A better transfer of torque from the wheels to the frame was obtained. This gives a better feeling of control over the handling of the wheelchair. Dural is an economically advantageous material for production, which also meets the prerequisites for the necessary functionality.

2.2 Modifications of individual components

In the Figure 2 (A) is the original adjustable construction. As it is better for the healthy partner to have the wheelchair higher and thus have better contact with the wheelchair user. The height of the beam was increased from the original 8 cm to 15 cm. The new beam is fixed and not adjustable.

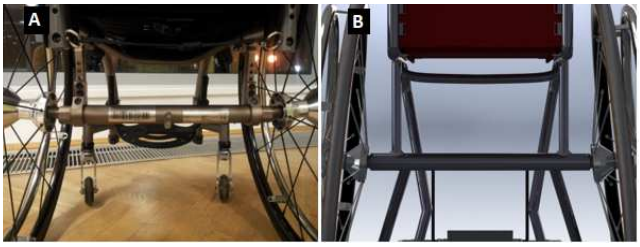

Figure 2 Beam before (A) and after modification (B)

The center of gravity (Figure 3) was satisfactory, the change was only the welding of the beam to the frame.

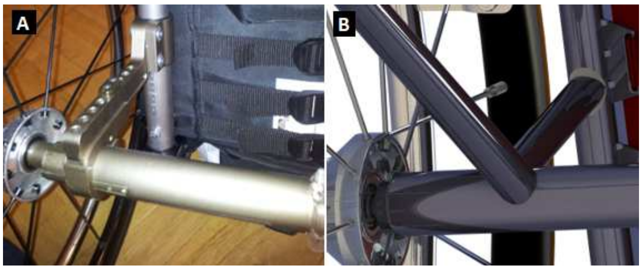

Figure 3 Center of gravity before (A) and after adjustment (B)

The modification (Figure 4) concerned the adaptation of the original frame to a mechanically closed structure. Which consisted in welding a part of the frame between the central axis and the front lower part of the frame.

Figure 4 Frame before (A) and after modification (B)

The inclination (Figure 5) of the wheel remained unchanged, as the characteristics of the truck were satisfactory. The hub was welded to the axis of the frame.


Figure 5 The inclination of the wheels was unchanged but fixed firmly

Better stability of the wheelchair (Figure 6) was ensured by changing the front wheels from 76.2 mm to 101.6 mm.

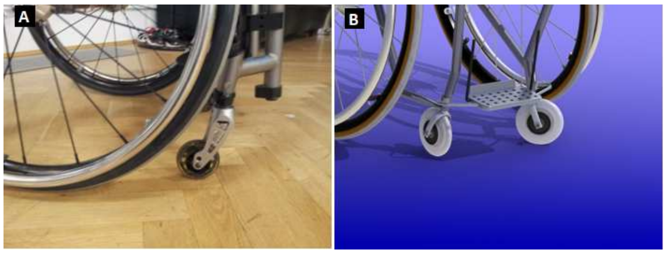

Figure 6 Front wheels before (A) and after modification (B)

Due to the dancer's weight loss, the seat part of the wheelchair was modified, which was narrowed by 15 mm on each side (Figure 7).

Figure 7 Original (A) and modified seat (B)

The reduction (Figure 8) of the backrest was due to better mobility of the upper part of the body. The folding backrest has been converted to a fixed one, which reduces the weight and improves the wheelchair's fitment into the seat.

Figure 8 The original height (A) of the backrest and its reduction (B)

3 Results and discussion

Finally, visualization was realized through the extension of the *Solidworks* software - *Photoview 360*. The dimensions of the wheelchair in question for the dimensional design of the modified components were obtained based on consultations with the distributor. Subsequently, the design part of the wheelchair and parts of the modifications were designed. Individual adjustments were also adapted after discussion with the user. Modeling of the wheel rim was done first. Subsequently, the mantle and hoop were modeled. Next, the modeling of the front wheel was continued, as the wheel size was first designed according to the catalog values. Then the fork of the wheel attachment was adapted. The bearings were chosen from the program superstructure, which can recalculate the required space for the bearing and select a suitable bearing

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from the selected standard (Figure 9 - Figure 12). The same method was used to select bearings for large wheels. The core was the modeling of the frame, which consisted in modeling half of the frame and subsequent mirroring. In the end, we modeled: the axis of the wheels, the limiting ring, the screw with the nut for the small wheel, the seat, and the backrest. These dance wheelchair components were finally put into the *assembly* and a complete model was created, which was visually modified. Adaptive sports and recreation are among the most effective ways for improving results during medical rehabilitation, changing people's perceptions of themselves, and promoting broader inclusion of individuals with disabilities in society [5].

Figure 9 Front view

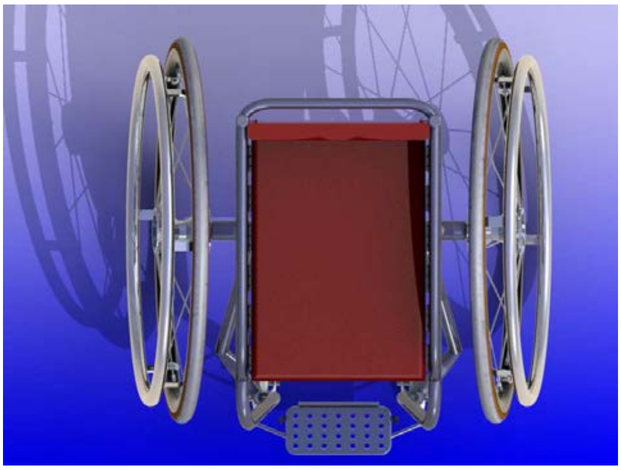

Figure 10 View from above

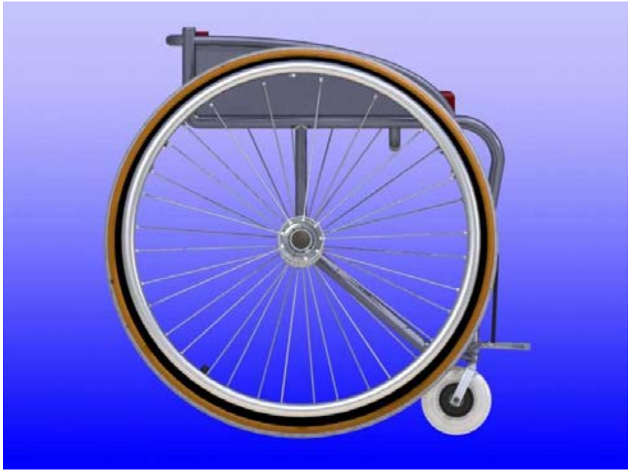

Figure 11 View from the left

Figure 12 Spatial view

4 Conclusions

As part of the personalization of the dance wheelchair, changes were in the beam, center of gravity, modification of the frame, attachment of the hub to the axis of the frame, replacement of the front wheels, narrowing of the seat, and lowering of the backrest. A higher resistance of the wheelchair to wear and tear and misalignment of individual settings during dance sports was achieved. Increasing the sitting position results in better interaction between the healthy partner and the seated wheelchair dancer.

The personalization of dance wheelchair contributes to the development of this sport and the increase of self-realization of disabled dancers.

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Ergonomic analysis of the classroom using the LiDAR system

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Keywords: LiDAR, 3D scanning, ergonomics, standards of the working environment.
Abstract: This article presents an innovative method of using LiDAR technology to analyze and measure the current ergonomic conditions of a university classroom. The purpose of this research is to provide a detailed analysis of the working environment and to identify collision points, proposing changes and improvements to meet the rules and standards of ergonomic correctness. The outcome of this analysis is a 3D model containing detailed information about the current state of the environment. This model was subsequently utilized to identify ergonomic deficiencies, which formed the basis for proposed modifications. The article also discusses the applications of modern LiDAR technology, its functions, and accessibility for ordinary users, as well as accessibility on individual software platforms.

1 Introduction

LiDAR (Light Detection and Ranging) is a remote sensing technology that uses pulsed laser light to measure distances and create highly detailed and accurate 3D maps of the surrounding environment. The basic principle of LiDAR involves sending out laser pulses and measuring the time it takes for the light to reflect back after hitting an object. By knowing the speed of light and the time it takes for the laser to return, the distance to the object can be calculated with high precision [1].

The LiDAR system typically consists of the following components:

1. Laser Source: The device emits short and powerful laser pulses, usually in the near-infrared spectrum.
2. Scanner and Optics: The laser pulses are directed toward the target area using scanning mirrors and lenses, allowing the LiDAR sensor to cover a wide field of view.
3. Photodetector: The sensor measures the intensity of the reflected laser light, capturing the time of flight information.
4. GPS Receiver: Integrated with the LiDAR system to obtain accurate geolocation data for each point in the generated point cloud.
5. Inertial Measurement Unit (IMU): This component records the orientation and motion of the LiDAR sensor, enabling precise spatial alignment of the collected data.

The characteristics of this method are speed, non-contact, precision, complexity, and simplicity of the work, which takes place automatically after setting the correct parameters in the device [2].

The output from the scan is the scanned object displayed in the form of point clouds (Figure 1), which can be further studied in applications or worked with and modified in CAD/CAM systems [3].

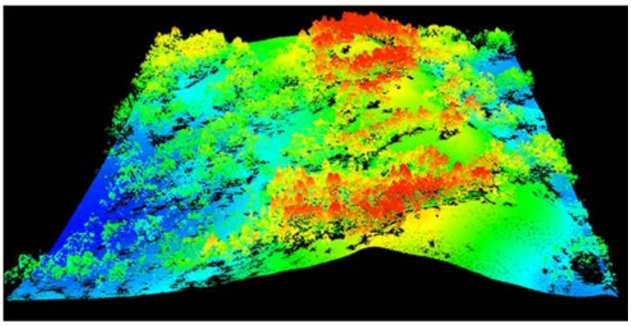

Figure 1 Point cloud captured by the LiDAR system [2]

Professional practical use of LiDAR is versatile in today's advanced age. This technology speeds up and simplifies many processes that would otherwise take unnecessary time and excessive human effort. This technology has found application in Topographic Mapping, Environmental Monitoring, Autonomous Vehicles, Urban Planning, Archaeology and Cultural Heritage, Forensics, and Accident Reconstruction [2,3].

1.1 Overview of selected applications for 3D scanning of rooms using the LiDAR system

Several room scanning applications were selected for this study. When choosing applications, the focus was on their usability in interiors, measuring tools, and, last but not least, on exporting scans to STL, OBJ or other types of files for surface mesh. Some types such as OBJ contain not only export to surface mesh but also texture data at each point of the scan, which facilitates additional evaluation in external applications such as e.g. GOM Inspect (Carl Zeiss, Germany), which provide significantly wider options for the dimensional and geometric evaluation of scans and their parts.

Obtained scans or their parts (models of equipment, devices, people, etc.) can be used in environment design software, simulation software, architecture, and other fields. As part of the research, their use was aimed at 3D scanning the laboratory, obtaining measures for ergonomic evaluation of its suitability, and subsequent evaluation of the laboratory based on the publication "Architects' Data" publication by the author Ernst Neufert [4].

For research purposes, SiteScape (SiteScape Inc., New York, USA), Scaniverse (Niantic, Inc., San Francisco, USA), Canvas (Occipital, Inc., Colorado, USA), Polycam (Polycam, Altadena, USA) and 3D scanner app (Laan Labs, NewYork, USA) software were used as reference software. Table 1 shows the basic parameters of the selected software.

Table 1 Summary of selected application parameters

Title	Site Scape	Scaniverse	Canvas	Polycam	3D Scanner App
Demo	Free	Free	Free scan	Free	Free
PRO	$37,50 12/ month $49,99/ year	Free	2D $0,1/ft 3D $0,15/ft	$6,99/ month $54,99/ year	Free
iOS	✓	✓	✓	✓	✓
Android	X	X	X	✓	X
Interior	✓	✓	✓	✓	✓
Exterior	X	✓	X	✓	✓
Rating	4,6/5	4,8/5	4,6/5	3,5/5	4,8/5

1.1.1 SiteScape

SiteScape is one of the most used LiDAR applications. It is available for download only for devices with the iOS operating system, i.e. iPhone 12/13 Pro, iPhone 12/13 Pro Max or iPad Pro 2020/2021 from Apple Inc. SiteScape was created by SiteScape Inc. The application is created to facilitate work in the fields of construction, engineering and architecture at a professional or amateur level. When scanning, it is possible to choose from two scanning methods, the usual method or Multi-scanning. The normal scan function simply starts scanning the surrounding space and collecting data until we end the scan with a button on the display. This scan cannot be interrupted with the option of continuing data collection later. The multi-scanning function works by gradually creating scans of the areas we are interested in. These scans can be synced to iCloud, and after logging into a desktop or laptop computer, they can be downloaded and then manually assembled and arranged to look like the complex of scanned spaces in reality. This process is accompanied by the help of artificial intelligence in the application, which automatically filters out the noise between the scans and helps us merge these scans into one (Figure 2). The application can scan a maximum of 500 m².

Among the disadvantages of this application can be included the inability of the application to capture nature and the external environment in such a way that the captured data creates an image and a surface that would be further usable [5].

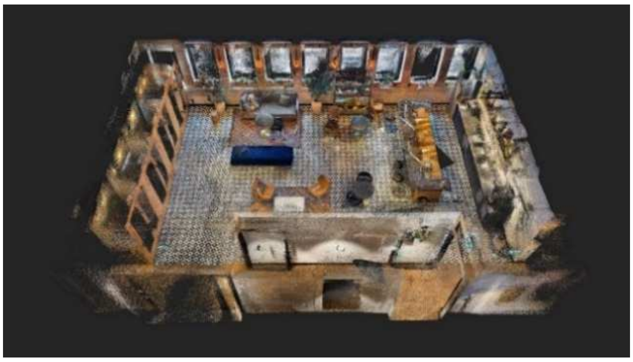

Figure 1 3D scan of the room by SiteScape [6]

1.1.2 Scaniverse

Scaniverse is an app from Toolbox AI that is fully compatible with iOS devices only. The devices that have full support are iPhone 12/13 Pro/Pro Max or for iPad Pro 2020 and other devices of higher orders. The advantages of this application include the ability to scan anything in space - for example, a room, an object even nature, and the outdoor environment with high accuracy. Another advantage of Scaniverse is that the generated scans can be shared with any other devices, where the user can view them through the browser installed on the device. The variety of export options is very refined, as models can be further imported into 3D modeling software such as Blender, Maya or SolidWorks. It is also possible to import 3D models into game creation programs such as Unity and Unreal Engine and use them, for example, to create game textures [7].

1.1.3 Canvas

The Canvas application is fully compatible only with devices from Apple Inc., specifically for iPhone 12/13 Pro/Pro Max devices or for iPad Pro 2020 and other devices of higher orders. The application is created by Occipital, Inc.

This application is mainly used in the professional sphere. It offers many features, making it ideal for design firms, kitchen and bathroom renovators, general contractors, interior designers, architects and other engineering industries to work with. Canvas can be used to scan 3D models of rooms and floor plans based on recorded measurement data after scanning.

Among the advantages of this application is that the application can create a 3D model from the measured data, from which the measurements of all objects that are scanned can then be read. The creators state the accuracy of the measurement with this application to be 3 cm, but it depends on the precision of the user.

The created model (Figure 3) can later be opened in AutoCAD and worked with. Export of models is possible

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in formats for CAD and BIM software, SketchUp, Chief Architect, Autodesk Revit, or 2020 Design programs [8]. Individual scans and models can also be shared and explored on any device.

Figure 2 3D scan of the room by Canvas [9]

1.1.4 Polycam

The Polycam application is an application from the App Store for iOS devices and is also compatible with Android devices, where it can be downloaded from the Google Play Store. For full use of the application's capabilities, it is necessary to download the application to a compatible device with a LiDAR sensor, specifically for models from Apple Inc. iPhone 12/13 Pro/Pro Max or for iPad Pro 2020 and other higher-end devices or for Android devices such as Samsung Galaxy S10 5G, S20+ and S20 [10]. The application was developed by Polycam.

The application has a simple interface and the process of obtaining data for the creation of a 3-dimensional model can be carried out in two ways.

1. Method of recording material:
   a. by starting the video,
   b. by gradually creating photos (photogrammetry).

2. In-depth data collection method:
   a. using LiDAR,
   b. without using LiDAR.

The speed of data generation is indicated by the manufacturer at 42 m^2/4 min. After finishing data processing, it is possible to view the model directly in the application.

The advantage of this application is the ability to create plans as images that can be shared between multiple devices at will. The accuracy of this application is given by the creators at 3 cm. A big advantage is also that the community that uses this application includes several thousand members, with whom you can actively communicate and advise via Discord or Gmail in case of problems during use. This application is capable of scanning both the interior and exterior. Export of scanned data is possible in several formats, for example, .obj, .png, .glb, .fbx, .dae, .stl, .usdz, .dxf, .ply, .laz, .pts, .gltf, .xyz. It is also possible to save a recording video or individual screenshots [11].

1.1.5 3D Scanner App

LiDAR scanning is also possible using the 3D Scanner App. This application is only compatible with devices from Apple Inc. with the iOS operating system, namely for iPhone, iPad, and iPod touch with iOS 14.0 and higher and for Mac with iOS 12.0 and higher. The creator of this application is Laan Labs.

3D Scanner App is designed and developed for 3D and CAD designers and architects.

Export from this program is possible in several formats. For example OBJ, STL, USDZ, WEB Link, GLTF, GLB, PCD, PLY, PTS, XYZ, LAS, e57, Sketchfab, DAE and FBX. It is also possible to send completed scans via the Apple iMessage application.

2 Methodology of scanning rooms and objects

Based on the review, four room scanning applications were selected.

Before the actual scanning, there are several steps to be taken to ensure the best possible result. These actions are aimed both at the device used for scanning and at the scanned environment. Individual steps are shown in Figure 4.

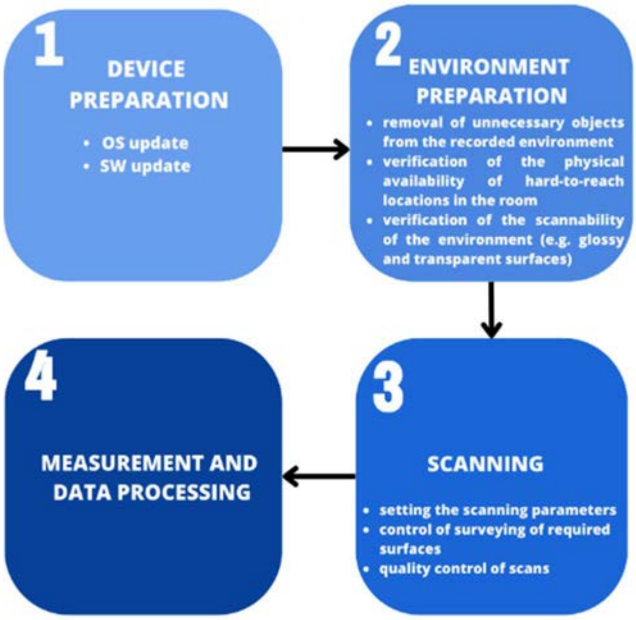

Figure 3 Room scanning methodology

As soon as the **SiteScape** application is turned on, it displays the activated camera, settings button, scan start, and gallery as the main menu. Before scanning, it is necessary to set the point density. From the options small, medium, and high density, large was chosen for the most accurate results. Another important setting is the point size when scanning (Point size), the largest point size was also chosen due to the size of the classroom. Additional options in the settings require the purchase of the Pro version of this application.

After pressing the button, the scanning is activated and the contours and shapes of the scanned surfaces are created on the screen with the simultaneous slow movement. The scanning process is limited by the amount of data and will automatically end when it is full. Scans that have been successfully performed will be displayed in the form of a 3D model after the scan is complete. This model can be exported and synchronized with the Cloud (Sync to Cloud). In the available gallery, it is possible to view all performed scans and continue to work with them.

Before starting the scan in **Scaniverse**, it is important to go into the settings and adjust some of them. When we have the application set up correctly, to activate the scan, click on the bottom bar, and start a new scan. A window will appear in which we choose the size of the object to be scanned. You can choose a small object (Small Object - e.g. food, toys, animals, flowers...), a medium object (Medium Object - e.g. people, vehicles, furniture...), and a large object or area (Large Object/Area - e.g. room, building, outdoor space...). The correct selection of the object from the menu does not affect the accuracy of the data, but only the default distance to which we want to shoot. Since the goal was to scan a classroom, the large object option was chosen. Before activating the scan, it is possible to set the maximum data scanning distance (Range). The range offered is from 0.3 m to 5 m, while a distance of 5 m was chosen due to the size of the room.

After activating the scan, it was necessary to scan the entire room with smooth, slow movements. If the movement was too fast, a warning appeared on the screen to slow down. It is possible to pause the scanning process and during it, it is possible to move freely in the space. However, when starting it again, it is important to have the device pointed at least partially at the already scanned surface, otherwise there may be a problem with the alignment of the scans. On the screen during scanning, there is a white-red striped field that indicates unscanned surfaces that need attention - for example, from a different angle or distance. The already scanned area is displayed on the screen as it is in reality.

After the scan is finished, the option to choose from 3 different modes for processing the scanned data will be displayed. The accuracy of the generated data depends on it. The first, fast mode "Speed" is intended for a quick generation with the smallest accuracy of the generated data to 10 mm, the second "area" mode is intended for generating larger areas with an accuracy of 5 mm, and therefore this option was used. The last "detail" mode uses photogrammetry and is recommended for displaying textured objects.

After choosing the desired mode, the application creates a network (Mesh) and the process is finished. A 3D model will appear on the screen. Finally, it is possible to save the scanned data even before generating the 3D model (Save Raw Data). It is important to keep them in case additional processing in another mode is required.

This 3D model is saved to the library in the application where it can be viewed. The application offers the possibility of editing, displaying in artificial reality, measurement of individual lengths, and the possibility of sharing the 3D model.

After opening the **Canvas** application, the main menu (Homes) will appear, where we can choose an already created or create a new project. Contains a library of all projects. All three room scans were inserted into the created project. In the main menu there are also orders (Orders), where you can save generated 3D CAD models and plans of scanned rooms, help (Help), where you can find a tutorial for use, and settings (Settings). In the settings, it is possible to determine the units of measurement and create models (Units). The meter (Meters) was chosen as the main unit.

Before starting the recording, it is important to adjust the room so that the conditions are optimal for creating the most faithful 3D model. It is necessary to turn on the light in the room, open the blinds and curtains and close the windows and doors. According to the instructions provided by the manufacturers of the Canvas application, it is necessary to start scanning from the corner of the room, on furniture, or on another surface that is not completely flat and monochromatic, such as a wall. After activating the scanning process, a real image of the environment at which the scanner is aimed is displayed on the screen. Along with it, gray triangles are also created indicating the area that has already been scanned. To correctly scan the room, it is necessary to move horizontally up, to the side, horizontally down, and continue again to the side that we chose the first time. The distance from the scanned surface should be 0.9144 - 3.048 m at all times. This procedure is repeated until the entire surface of the room is scanned. The surface of the mirrors is omitted, only the area around them is scanned.

The scan can be interrupted or terminated at any time with the pause button. The location that was last scanned will remain on the screen until it is restarted. It is necessary to continue scanning on it. After finishing the scanning of the surface, we have the option to generate a CAD plan (Get CAD), for which it is necessary to pay, or we can see a scan without colors (View Scan) - that is, a gray scanned surface. The application allows you to apply colors to the scan for free so that it looks like in reality.

Scans can be viewed from a point of view as if the observer were inside the object, outside, or from above. Exporting scans for free is limited to a URL link that allows the scan to be shared and viewed on other devices. The application allows measuring the lengths and contents of surfaces in the preview of the scans using a toolbar that can be pulled from the right side of the screen with an arrow.

Scanning can be interrupted or terminated at any time by pressing the "pause" button. The location that was last scanned will remain on the screen until it is restarted.

It is necessary to continue scanning it. After finishing the scanning of the surface, the option to generate a CAD

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plan (Get CAD) is displayed, for which it is necessary to pay, or we can see a scan without texture (View Scan) - that is, a gray scanned surface. The application allows you to apply colors to the scan for free so that it looks like in reality.

Scans can be viewed from a point of view as if the observer were inside the object, outside, or from above. Exporting scans for free is limited to a URL link that allows the scan to be shared and viewed on other devices. The application allows measuring the lengths and contents of surfaces in the preview of the scans using a toolbar that can be pulled from the right side of the screen with an arrow.

The 3D Scanner App facilitates various scanning methods. Upon opening, it presents the camera along with options to select the scanning method, initiate scanning, and access old scans. We opted for LiDAR scanning, which involves displaying a grid of triangles on the surface. Scanned triangles retain their authentic color, while non-scanned ones appear in red. While scanning, adherence to the fundamental rules of slow and smooth movement is crucial. The creators caution against scanning the same location twice, citing potential issues. Additionally, they note that the app might not accurately capture small surfaces, like pens or table legs, possibly interpreting them as empty space**.**

After the scan is finished, a color scan will be displayed composed of the texture of the surface that was scanned. Along with it, a table will be displayed from which you can choose how the scan should be processed (Process Scan). There are HD, Medium, Fast or Custom processes to choose from. The selected format was HD to keep the scan data as accurate as possible. This generated true color scan can be exported in various formats with the Share button. Scans can also be edited and smoothed with various functions that appear under the button edit (Edit) and more (More). It is also possible to measure individual lengths in the created scans, this function is activated with the Measure button.

3 Ergonomic analysis of the classroom from a 3D scan

Nowadays, there is an excessive load and overloading of the human body in workplaces due to incorrect ergonomic design of the equipment in classrooms, laboratories, and other workplaces. Such workplaces do not meet the standards according to which they should have been originally designed. By means of the LiDAR technology built into the applications and their other functions, it is possible to simplify the design of an ergonomically suitable environment or to transform an originally unsatisfactory one.

3.1 Ergonomics of the classroom

When defining the basic ergonomic parameters of the classroom, the publication “Architects' Data” by the author Neufert et al. It was the version from 2019 that was used. The publication is considered among architects as a source of standards in the professional community. The following parameters were selected for evaluation [4].

a) Workplace:
i. Table (depth, width, height),
ii. A chair.

b) Parameters for the classroom:
i. Dimension behind the table,
ii. The dimension behind the table in the last row,
iii. The size of the main street,
iv. Space for manipulating the window,
v. Access to the sink,
vi. Normative m^2 for one workplace,
vii. The dimension between the board and the first row of benches.

Figure 5 shows the overall scan of the laboratory with the measured values between the selected locations.

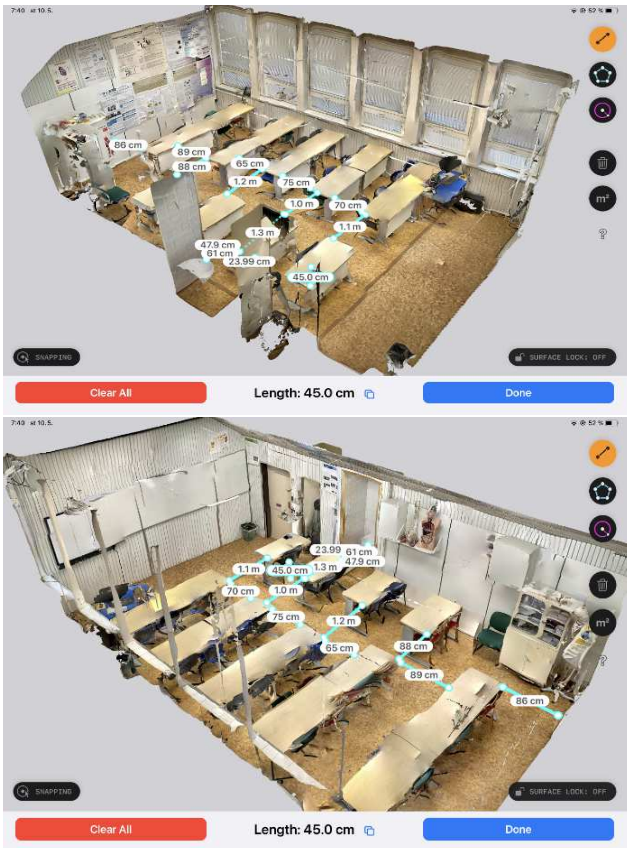

Figure 4 3D scan of the classroom with dimensions

Table 2 shows standard values and actual values for selected parameters with an assessment of whether the value is sufficient, partially sufficient, or insufficient.

Table 1 Evaluation of compliance with standards in classroom

Parameter number	Parameter name	Actual dimension	Standard*	sufficient /insufficient
1A	Table - height	0,75 m	0,75 m	complies with the standards
1B	Table for 2 people - width	1,3 m		
1B	Working width for 1 person	0,65 m	0,58 m - 0,70 m	complies with the standards
1C	Table - depth	0,65 m	0,65 m	complies with the standards
2	Chair height	0,45 m	od 0,42 m do 0,52 m	complies with the standards
3A	Dimension behind the table	od 0,65 m do 0,89 m	0,85 m	partially meets the standards
3B	The dimension behind the table in the last row	0,86 m	0,95 m	Does not complies with the standards
4	Central aisle	od 0,88 m do1,2 m	od 0,9 m do 1,20 m	partially complies the standards
5	Space for manipulating the window	0 m	0,55 m	Does not complies with the standards
6	Access to the sink	0,61 m	od 0,80 m do 0,90 m	Does not complies with the standards
7	Classroom area 47.32 m^2 / number of workplaces	1,69 m2	2 m2	partially complies the standards

*The mentioned standards were taken from publication Architects' Data by the author Ernst Neufert [4]

Figure 6 shows the proposed floor plan of the room with dimensions.

Figure 5 Ergonomic design of the classroom

4 Results and discussion

From the scans of the classrooms that have been created, it is possible to read the data needed to design the ideal ergonomically suitable environment for the student's workplace and the correct parameters for the classroom. It was found that the height of the tables is 0.75 m, which meets the prescribed standard. The working width and depth of the table were measured to be 0.65 m and 0.65 m, respectively. These values correspond to standard sizes.

When measuring the parameters for the classroom, the dimension behind the desk was measured, i.e. the space for sitting, which varied from 0.65 m to 0.89 m between the individual benches. This dimension should have a minimum value of 0.85 m and thus only partially meets the prescribed value. The dimension behind the table in the last row should be defined at 0.95 m with the assumption that it will be necessary to walk smoothly along the wall behind it. The dimension behind this table was measured at 0.86 m, which does not meet the minimum standard. The size of the main aisle in the classroom also varied from 0.88 m to 1.2 m. The standardized size of the main street should be from 0.9 m to 1.20 m and thus partially meets the requirements. The space for manipulating the window was 0 m. In this space, there should have been an aisle with a width of 0.55 m for proper handling. This space is also important for maintaining hygiene in the classroom through ventilation. In front of the sink in the classroom there was a table with chairs and it prevented access to it. According to the standards, access to the sink should be ensured by an aisle with a width of 0.80 m to 0.90 m. The distance between the first bench and the board should be around 2 m, but this dimension was not precisely defined in the “Architects' Data” publication [4]. As the last parameter, we calculated the area of the classroom. We divided this dimension by the number of jobs. According to the current layout of the classroom, we found that the working area for one student is 1.69 m^2, which does not meet the required standards.

Based on the set of standards, the norm for one workplace in our type of classroom is recommended and defined at 2 m^2. The size of our room is 47.32 m^2 and the recommended number of workplaces is 23.66. We compared this data with the result of the arrangement resulting from the application of rules i - iv.

5 Conclusion

In conclusion, the analysis of ergonomics in a university classroom through the implementation of 3D scanning technology has proven to be an invaluable and transformative tool. By employing 3D scanning techniques, we were able to comprehensively capture and evaluate the spatial layout, furniture arrangement. The data collected provided measurements and visual representations, enabling a comprehensive understanding of the current ergonomic conditions and potential areas for improvement.

The findings of this study revealed several crucial insights. Firstly, it was evident that the existing classroom design had both strengths and weaknesses in terms of ergonomic functionality. Through this analysis, we were able to recommend targeted interventions to enhance the overall classroom ergonomics. By optimizing furniture placement, adjusting seat heights, and incorporating adjustable features, we can create an environment that promotes better posture, reduces physical strain, and supports overall student comfort. Additionally, the insights gained from this study can guide the future design of university classrooms to prioritize ergonomics from the outset, benefiting both students and educators. The integration of such technology can revolutionize the way we approach classroom design and ergonomic evaluations, leading to more inclusive, comfortable, and conducive learning spaces.

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Technology and possibilities of recycling catalysts

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Keywords: catalysts, recycling, PGM, materials, technology.
Abstract: The presented article focuses on the possibilities of recycling three types of catalysts. These catalyst types will undergo examination, measurement, and analysis with the aim of identifying which of these catalysts contains the necessary number of precious metals (PGM - Platinum Group Metals). PGM metals are among the rarest and most challenging-to-obtain elements on Earth, carrying a high risk of supply shortage. Nevertheless, they are crucial for the European Union (EU) and the automotive industry. Not every catalyst used in the market is suitable for recycling due to the absence of these precious metal particles.

1 Introduction

In the dynamic environment of modern industry and technological advancement, the concept of sustainability has emerged as a primary aspect. As societies strive to achieve a harmonious balance between economic growth and environmental care, the critical role of recycling processes becomes increasingly evident. Among these processes, catalytic recycling stands out as a key player on the path to a more sustainable future.

The necessity for catalysis recycling becomes even more apparent when considering the intricate composition of modern catalysts. Numerous industrial catalysts are designed with complex structures that incorporate rare and precious metals like platinum, palladium, and rhodium, collectively known as Platinum Group Metals (PGMs). These metals, acclaimed for their exceptional catalytic properties, confront a challenging paradox. While propelling the development of sustainable technologies, their scarcity and associated geopolitical intricacies pose significant supply chain risks. This dual nature of PGMs intensifies the urgency to implement effective recycling procedures that ensure the responsible and efficient utilization of these valuable resources.

The need for catalytic recycling goes beyond the scope of resource conservation. It deeply resonates with the global effort to reduce the ecological footprint of various industrial sectors. Given that catalytic processes are an integral part of sectors such as energy production, transportation, and chemical manufacturing, the effective recycling of catalysts contributes to reducing energy consumption, lowering emissions, and minimizing waste generation. These outcomes align with international sustainability goals and regulatory frameworks aimed at mitigating climate change and promoting a circular economy [1].

2 Prepare of identification of sustainable catalyst

The identification of each used catalyst depended on the container code. The main characteristics of each catalyst included the car model and catalyst type. The type of catalysts was verified based on the metal content after chemical analysis [2].

Table 1 Identification of 3 catalysts on market [3]

Number	Canister code	Model Car
1	13106917	Opel Astra H
2	8200358551, C114	RENAULT ESPACE, 2200CC, DIESEL
3	3B0131701Q, 8D0178E, GLH	AUDI A6, 2400CC, DIESEL

Each catalyst was disassembled and de-canned to remove the metal container and obtain the ceramic catalyst, which was prepared for physic-chemical characterization. The decanting process was conducted carefully to prevent the fracture of the ceramic monolith inside, allowing the evaluation of weight and dimensions [2].

Table 2 Dimension of catalyst [3]

Number	Weight, g	Height, cm	Diameter, cm
1	952.30	9.7	20.1
2	1026.75	14.4	10.7
3	573.50	11.9	11.4

The acquired dimensions of each catalyst were measured according to their shape. For cylinder-shaped catalysts, weight, height, and diameter were measured. Each ceramic catalyst was pre-processed for microscopic analysis and elemental analysis (XRF). The pre-processing involved steps of grinding, milling, and sieving to reduce the particle size below 250 µm. During the grinding phase, small pieces were taken from each catalyst, which underwent analysis by optical microscopy for cell observation and measurement of their dimensions [2].

3 Results - analysis through optical microscopy

In the context of analyzing three different catalysts used in the study, an optical microscope from the AmScope ME520 (Figure 1) series was employed, along with the corresponding software. The data was acquired at a total magnification of 125x. A detailed description of the obtained information regarding each catalyst follows [2].

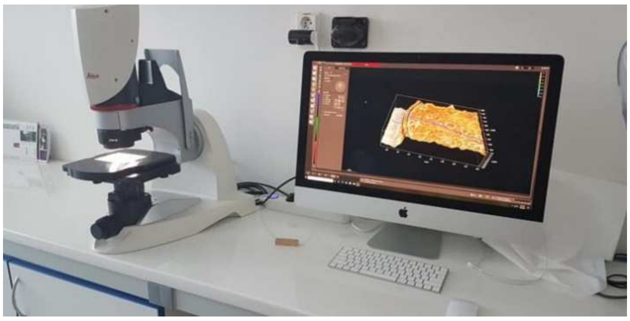

Figure 1 AmScope ME520 [5]

3.1 Process of identification of sustainable catalyst via optical microscopy

Catalyst 1

Two minor fragments were gathered (Figure 2) from the exhausted catalyst for the purpose of capturing images from various regions under the optical microscope, wherein the density of cells and the thickness of the ceramic monolith walls were assessed [2].

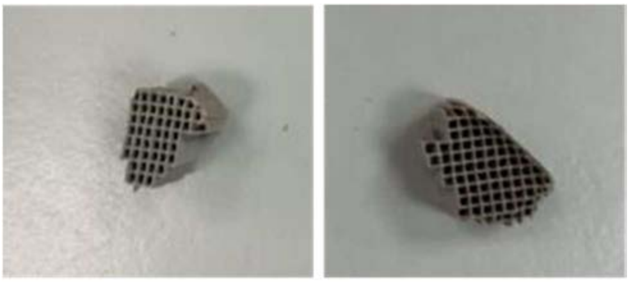

Figure 2 Pieces from catalyst number 1 [3]

Utilizing the optical microscope images, the density of cells and the thickness of the monolith's washcoat were evaluated. The findings derived from the optical microscope revealed an estimated cell density of around 527 cells per square inch (cpsi). Furthermore, measurements and calculations yielded a cell wall thickness of 0.193 mm and a washcoat thickness of 0.049 mm.

Catalyst 2

To gain visual insights from diverse regions under the optical microscope, two minor fragments were gathered (Figure 3) from the exhausted catalyst number 2. This facilitated the assessment of cell density and ceramic monolith wall thickness. The images obtained through the optical microscope were also utilized to gauge the cell density and washcoat thickness of the monolith. Specific regions (Figure 4) were chosen to quantify the catalyst's cell density [3].

Figure 3 Pieces from catalyst number 2 [3]

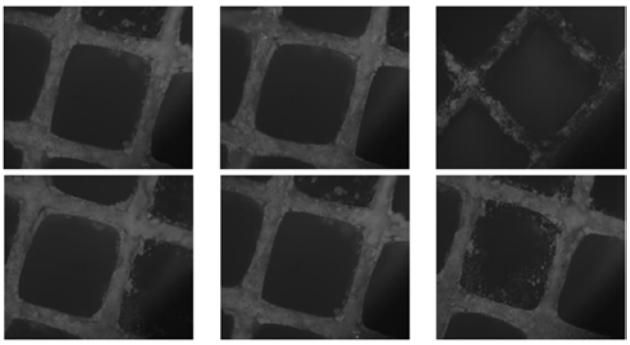

Figure 4 Optical microscope images from catalyst number 2 [3]

Catalyst 3

To capture a variety of perspectives under the optical microscope, two minor fragments were gathered (Figure 5) from depleted catalyst number 3. This procedure aimed to measure the cell density and the thickness of the ceramic monolith's walls. The cell density and the washcoat thickness of the monolith were determined based on the images obtained through the optical microscope. Specifically designated regions, (Figure 6), were chosen to quantify the catalyst's cell density [3].

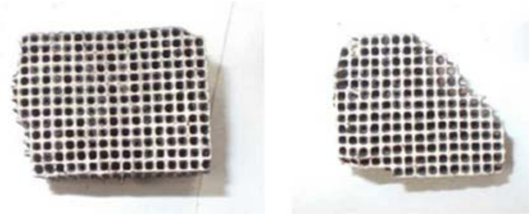

Figure 5 Pieces from catalyst number 3 [3]

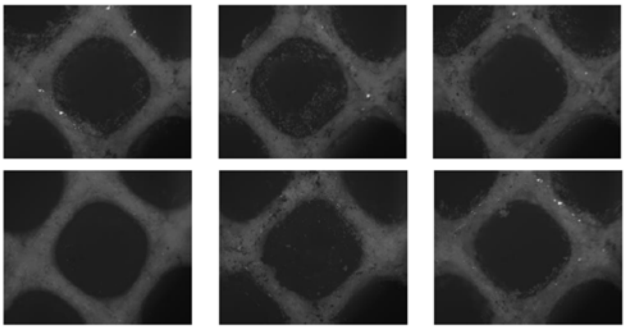

Figure 6 Optical microscope images from catalyst number 3 [3]

3.2 Chemical analysis

In the realm of elemental analysis, the importance of preliminary processing and accurate sample selection cannot be overstated. For every ceramic catalyst, an individual procedure involved milling, ensuring that 80% of the sample achieved a particle size below 250µm, accomplished via a knife mill (Figure 7). The particle size of each sample was subsequently verified with sieves tailored for sizes below 250µm [5].

Figure 7 Knife mill [3]

Each sample underwent a process of homogenization and was subsequently divided into four distinct sections. To yield more comprehensive and representative outcomes, two minor samples were obtained. These were subsequently subjected to drying in a BINDER oven (120°C, 2 hours) (Figure 8), in preparation for XRF analysis aimed at quantifying the content of Platinum Group Metals (PGMs) [5].

Figure 8 Dryer [3]

3.3 X-ray Fluorescence (XRF) analysis

The loading of PGMs was ascertained using X-Ray Fluorescence spectroscopy. XRF analysis, a method characterized by accuracy, speed, non-destructiveness, and repeatability, eliminates the need for chemical preparation. Consequently, chemical reagents are unnecessary, thereby minimizing costs. The XRF spectrometer (Vanta Olympus 2017, Waltham, MA, USA) (depicted in Figure 20) comes with an inherent calibration from the manufacturer, allowing precise measurement of Pt, Pd, and Rh in used catalysts with average PGM concentrations of 1000ppm, 1700ppm, and 300ppm, respectively. Despite the existing calibration of the X-ray Fluorescence (XRF) analyzer, conducted an additional calibration to enhance the precision of XRF measurements. Through this supplementary calibration, Pd was calibrated within a loading range of 1270-2730ppm, Pt within a range of 614-2760ppm, and Rh within a range of 237-322ppm. The PGM content of the two minor samples from each catalyst was gauged, and their average was computed (Tab.3). The homogeneity of the catalyst samples was verified through these measurements [7].

3.4 Calcination process

As previously noted, the microscopic examination revealed the presence of organic residues within the structure of the catalytic converter. Consequently, a calcination procedure was undertaken on small-scale samples to quantify the mass of these organic deposits within each catalyst. Additionally, the calcined samples were subjected to XRF analysis to evaluate how these organic compounds influenced the detection of PGM concentrations. The quantification of organic deposits was based on the comparison of sample mass before and after the calcination process, conducted at a temperature of 750°C for a duration of 5 hours. The impact of calcination was evident through visual observation, particularly by noting the color alteration in the various samples [7].

4 Conclusion

In summary (Table 3), a total of 3 used catalysts were examined for the purpose of their comprehensive physicochemical characterization. This characterization encompassed catalyst identification, preprocessing, and XRF analysis. These steps aimed to prepare the samples for chemical analysis and determine the content of PGMs (platinum, palladium, rhodium). Calcination was performed to identify potential organic residues in each sample. The samples underwent XRF analysis before and after calcination to assess the impact of organic compounds on PGM detection.

Regarding the ultimate identification of the provided used catalysts, those containing rhodium and platinum or/and palladium were classified as Three-Way Catalysts (TWC). Conversely, catalysts primarily containing platinum or/and palladium were mostly identified as Diesel Oxidation Catalysts (DOC). Nevertheless, spent catalytic converters with low concentrations of platinum or/and palladium could potentially be labeled as Dual-Function Catalysts, considering additional information such as the vehicle model and manufacturing year [7].

Table 3 Final summary of the results of the three catalysts [3]

Number	Pt, ppm	Pd, ppm	Rh, ppm
1	-	1945	348
2	620	-	-
3	2434	-	-

As a result of this detailed analysis, the following research findings were obtained:

- Only catalyst number 1 is identified as a suitable for recycling thanks to the values of Pd and Rh.
- Only Pt was detected in the other catalysts [7].

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The influence of the cutting tool geometry on the surface quality of the parts manufactured by WAAM - Wire Arc Additive Manufacturing

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Keywords: milling, WAAM, measurement, thin-walled parts, end mill tools.

Abstract: Thin-walled components have extensive usage in the aviation, aerospace, automotive, and energy sectors. Wire Arc Additive Manufacturing (WAAM) additive technology is a technology that is used to produce thin-walled components by adding layers by layers. MIG/MAG welding technology is used in WAAM. The milling of thin-walled components often results in chatter, which causes waves on the milled surfaces. The variable helix angle reduces chatter during milling. The study found that a constant helix angle of 30°-30°-30° caused the active part of the wall to deflect towards the cutting tool, resulting in the least desirable outcomes. In contrast, cutting tools with 30°-30°-25° and 30°-30°-35° helix angles produced comparable results with minor surface waves.

1 Introduction

The main reason for studying the influence of the geometry of cutting tools on the surface quality of parts manufactured by WAAM additive technology is the milling of the surfaces made by wire arc additive manufacturing. WAAM is an alternative additive technology that combines an electric arc as a heat source and a welding wire filler material for individual welding layers to achieve the closest form of the component products [1]. For the parts layering used, MIG/MAG welding technology is combined with industrial robots or portal devices. This additive technology belongs to the ISO/ASTM standard 52 900. This process is a member of the Direct Energy Deposition (DED) category of additive manufacturing techniques. WAAM involves depositing layers of metal to create a 3D shape. Thin-walled parts are manufactured by WAAM technology [2]. Thin-walled parts are widely used in the aviation, aerospace, automotive, and energy industries. Due to its form and low rigidity, thin-walled parts can easily deform during milling [3]. Thin-walled part machining follows the WAAM technology. Milling is used to produce precise thin-walled parts. Chatter or vibration is significant during the milling of thin-walled parts. When milling tools are used for thin-walled milling, they cause conversation that creates waves on the machined surface of the part. There are several methods to remove the chatter during thin-walled milling or remove waves on the milled surfaces. The first method uses a stable lobe diagram to predict the regenerative chatter of milling [4-7]. The second method is the appropriate machining strategy (material removal method) for thin walls. Effective machining strategies significantly impact the surface quality of thin-wall parts [8,9]. The third method uses an end mill with a variable pitch [5,10-12] and a variable helix angle. The fourth method is to use sandwich elements [13,14] or to support workpieces or cutting tools support [15]. This study analysed the impact of the angle of the end mill helix on the surface quality of thin-walled AW 5083 aluminium alloy parts manufactured through WAAM technology after milling.

2 Materials and methods

2.1 Wire Arc Additive Manufacturing

Wire Arc Additive Manufacturing (WAAM) additive technology is used to manufacture thin-walled parts. The welding layers were located on the base substrate pad. The dimension of the substrate pad was 100 x 200 x 20 mm. Table 1 shows the chemical composition of the aluminium alloy 5083 for the substrate pad. Fabricate responses are shown in Table 2.

Table 1 Chemical composition of aluminium alloy 5083 [16]

Element	%
Si	0.4
Fe	0.4
Cu	0.1
Mn	0.4-1.0
Mg	4.0-4.9
Zn	0.25
Ti	0.15
Cr	0.05-0.25
Al	Balance

Table 2 Fabrication response for aluminium alloy 5083 [16]

Cold forming	Average
Machinability	Poor
Weldability – Gas	Average
Weldability – Arc	Excellent
Brazability	Poor
Solderability	Poor

Table 3 Chemical composition of wire electrode for aluminium alloy [17]

Element	%
Si	< 0.25
Fe	< 0.40
Cu	< 0.05
Mn	0.70 – 1.10
Mg	4.5 – 5.2
Cr	0.05 – 0.25
Zn	< 0.25
Be	< 0.0003
Ti	< 0.15
Zr	0.10 – 0.20
Others total	< 0.15

The wire was an aluminium alloy AW 5087. The diameter of the wire was 1.2 mm. The wire material was a special alloy AlMg4,5MnZr used to weld the aluminium alloy and the magnesium alloy. The thin-walled part was welded layer by layer using the Fronius TPS600i. The welding parameters are shown in Table 4. The MIG welding process was used to produce thin-walled parts. Three thin-walled parts were made on the substrate pad. Figure 1 shows three thin-walled parts and a sample that was used as a blank material for experimental milling. The preheating temperature of the substrate pad was 330°C, measured by a thermocouple.

Table 4 Experimental parameters of WAAM

Parameters	Value
Welding Current [A]	82
Welding Voltage [V]	20.9
A feed of wire [m/min]	5
Inert welding gas	Ar 4.6
Gas flow [l/min]	15-20
The preheating temperature of the substrate pad	300 °C

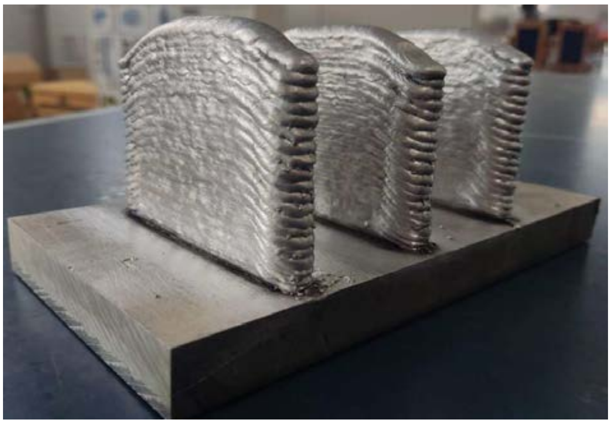

Figure 1 The sample manufactured by the WAAM technology

2.2 Design and manufacturing of cutting tools

The geometry of the milling tools significantly impacts the surface quality of thin-walled parts during milling. One of the investigated geometry parameters was the helix angle. A three-flute milling tool had a different helix angle in the third flute. The tooth pitch was 120°-120°-120°. NuMROTOPlus CAD / CAM software was used to design the milling tool with different helix angles. The helix angle was 30° - 30° - 30°, 30° - 30° - 25°, 30° - 30° - 35°. Figure 5 shows a 3D model of end mills. Table 5 shows the parameters that were used for designing milling tools. The three milling tools were manufactured by the Reinecker WZS 60. Sintered carbide CTS24Z from Ceratizit Group was used to produce end mills. The milling tools were made of cemented carbide.

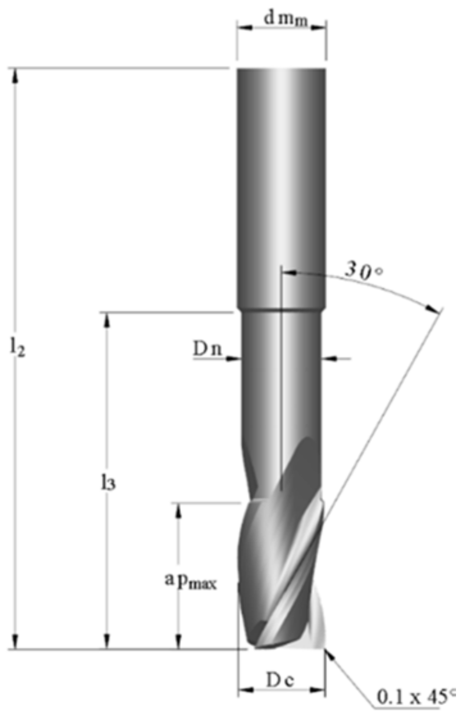

Figure 2 3D CAD model of the designed end mill

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Table 5 Geometry parameters for the design of end mills

Parameter of end mill	Value
Diameter – dmm [mm]	10h6
Diameter – Dc [mm]	10
Diameter- Dn [mm]	9
Length – l2 [mm]	72
Length - l3 [mm]	25
Max. depth of cut - ap_{max} [mm]	20
Pitch and division angle [°]	120 – 120 – 120
Teeth number - z	3
Helix angle [°]	30 – 30 – 30
	30 – 30 – 25
	30 – 30 – 35
Rake angle [°]	10
Relief angle [°]	10

2.3 Milling of the thin-walled part

The milling process was performed by the DMG HSC 105 linear. Table 6 shows the experimental parameters for the milling process. Two different depths of cut were used. The axial depth cut for roughing was 10 mm, and the axial depth cut for finishing was 5 mm. The final thickness of the thin wall was 2 mm after milling. The RDOC milling strategy was used [18]. The RDOC strategy will cause the cutting forces during milling to be smaller, and thus have less influence on the thin wall of the thin-walled part being milled. The milling strategies that have been considered to reduce vibrations:

- the use of the down-milling process, which exerts less pressure on the machined wall,
- use of higher cutting speeds and, at the same time, lower radial depths of cut,
- maintaining the 8:1 rule, which defines that the maximum axial depth of the cut should not exceed eight times the thickness.

The tool path milling strategy was generated via the PowerMill CAM software.

Table 6 Experimental parameters of milling

Parameters	Value
Cutting Speed [m.min-1]	1200
Spindle Speed [min-1]	31831
Feed [mm]	0,12
Roughing depth of cutting [mm]	10
Finishing depth of cutting [mm]	5
With of cut [mm]	3,2; 2,5; 1,5

The milling process was carried out without a cooling medium. On some levels of cutting (depth of cutting), the milling of a thin wall was accompanied by an unpleasant sound caused by the wall's insufficient rigidity during the cutting process. Three thin walls were milled from both sides. Figure 3 shows the milled surface of the thin-walled part by the end mill with helix angle 30°-30°-25°.

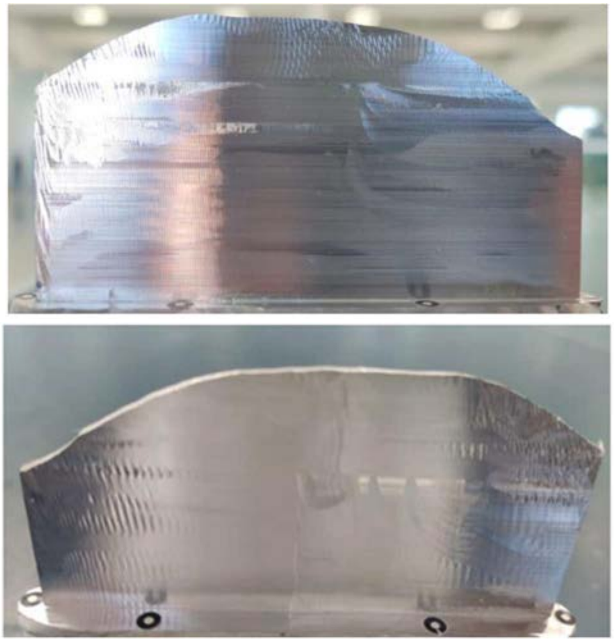

Figure 3 Thin-walled part after milling by end mill with helix angle 25°

Figure 4 shows the milled surface of the thin-walled part by end mill with helix angle 30°-30°-30°. Figure 5 shows the milled surface of the thin-walled part by end mill with helix angle 30°-30°-35°.

Figure 4 Thin-walled part after milling by end mill with helix angle 30°

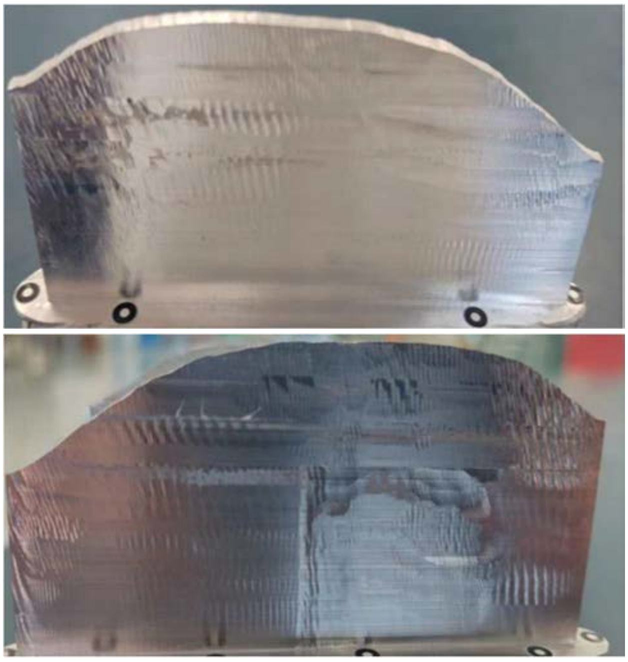

Figure 5 Thin-walled part after milling by end mill with helix angle 35°

2.4 Measurement of the quality of thin-walled parts

Quality measurement was carried out with the GOM ATOS II Triple Scan. The MV 320 measuring volume was used to scan the aluminium parts (Figure 6). The chalk spray was applied to avoid the shiny surface.

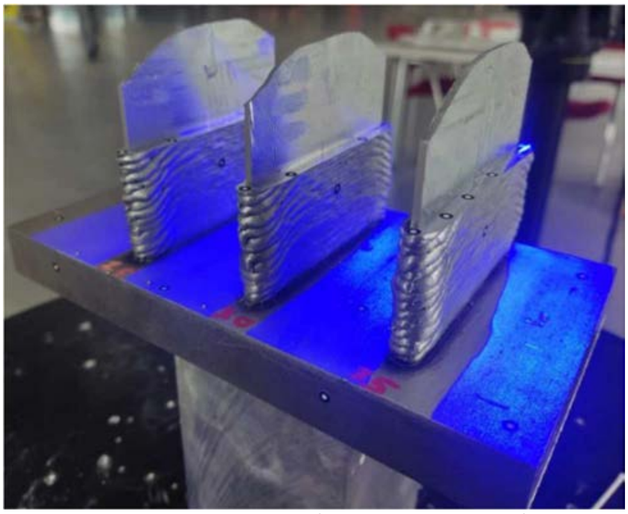

Figure 6 Optical 3D scanning of a thin-walled part after milling

3 Results and discussion

The quality evaluation of milled surfaces of thin-walled parts was realised by the CAQ software GOM Inspect 2001. Colour deviation maps are suitable for quality evaluation because we get a view of deviation information for all surfaces. The tolerance of the colour deviation maps was from +0,5 to -0,5 mm. Figure 7 shows the colour deviation maps of a thin-walled part that was milled by the end mill with a helix angle of 30°-30°-25°. The milled surface was without visible waves, as shown in Figure 3.

This helix angle combination reduces thin-walled parts vibration compared to other cases presented in this paper. The tool with a helix angle of 30°-30°-25° and 30°-30°-35° produces surfaces where a colour map of deviations includes a red and a strong blue colour. However, the waves on the surface are milder than those produced by the 30° cutting tool 30°-30°-30°. Figure 8 shows the colour deviation maps of a thin-walled part that was milled by the end mill with a helix angle of 30°-30°-30°. Figure 9 shows the colour deviation maps of a thin-walled part that was milled by the end mill with a helix angle of 30°-30°-35°.

By comparing the colour maps of the deviations, it was found that the use of a tool with an unconventional geometry positively affected the dimensional accuracy of the manufactured part.

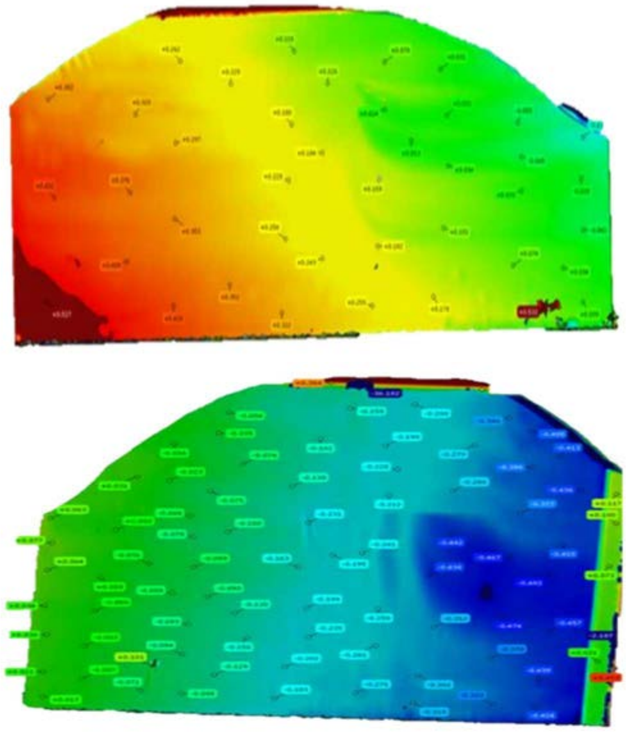

Figure 7 Colour deviation maps of thin-walled parts after milling – helix angle 30°-30°-25°

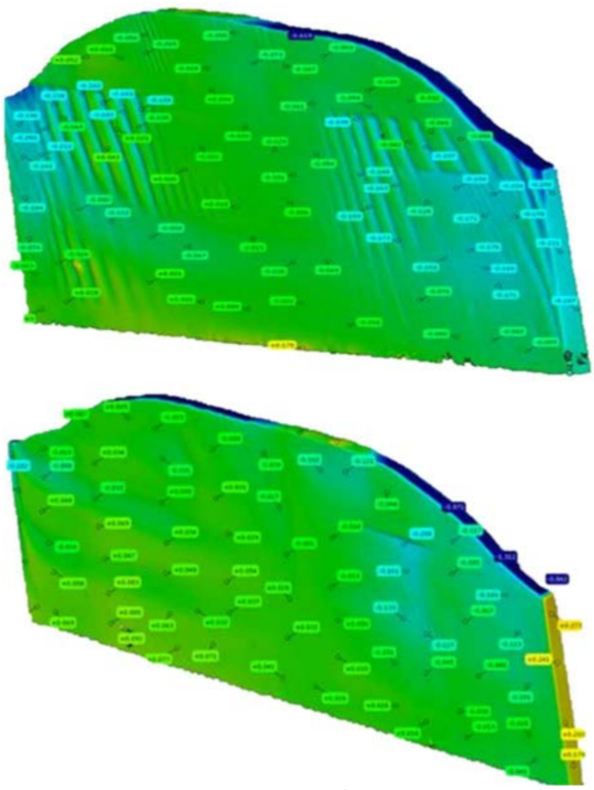

Figure 8 Colour deviation maps of thin-walled parts after milling – helix angle 30°-30°-30°

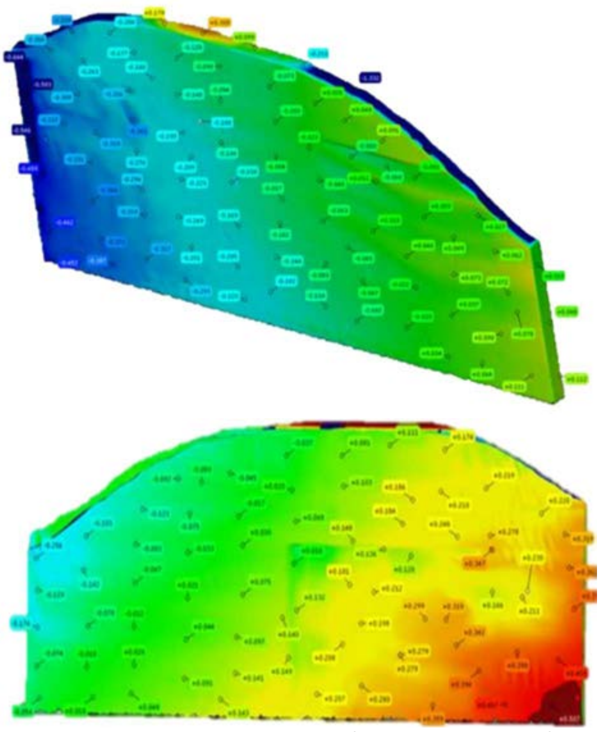

Figure 9 Colour deviation maps of thin-walled parts after milling – helix angle 30°-30°-35°

4 Conclusion

The study's outcome involves the assessment of colour deviation maps, revealing that employing a varying helix angle on the third tooth of the cutter yields favourable outcomes when machining thin-walled components. However, the wall's insufficient rigidity, coupled with frequent natural vibrations, leads to wavering and eventual bending due to its lack of strength. The observations above highlight that the least desirable results were obtained using the approach featuring a constant helix angle of 30°, causing the wall to deflect towards its active part of the cutting tool. In contrast, cutting tools with 25 ° and 35 ° helix angles yielded comparable results.

Acknowledgement
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The efect of characteristics of SMEs to the order processing and information system costs

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Keywords: logistics, order processing, information system, cost reduction, characteristics of small and medium enterprises (SMEs).

Abstract: It is apparent that the logistics process can reduce cost in order to have an efficient profit, efficient suitable and efficient economical way to run a sustainable business. This research aimed to study the effect of characteristics of small and medium-sized enterprises (SME) on the reduction of operating costs to get the most benefit and most suitable and the most economical way to run a sustainable business. A case study of logistics of small and medium-sized enterprise entrepreneurs in Pathum Thani Province by using questionnaires to collect 400 sets of data. The results of the study showed that the purchase order and the information system affected the reduction of operating costs. Participants responded the different registered capital of small and medium-sized enterprises (SME) have differences in managing cost systems, and the business uses information systems in the flow of information through electronic processes that are ordered by customers systematically with statistical significance at the level of 0.05.

1 Introduction

Enterprise management is an important part of enterprise management and an important factor that contributes to enterprise operations. It is apparent that logistics process can reduce cost in order to have the efficient profit, efficient suitable and the efficient economical way to run a sustainable business [1]. Logistics management is an important strategy that helps Small and medium enterprises (SMEs) can enhance their capabilities, compete and be able to earn more profits [2]. The main goal of logistics cost management can be divided into are two factors: 1) To reduce the total cost 2) To be able to respond to demand attract customers effectively, but to achieve goals [2]. Entrepreneurs, it is necessary to study the meaning, logistics management, main logistics activities, SME business logistics cost and profit management planning, analysis and calculating costs to determine. The distribution prices is considered to enable SMEs to manage the cost. Therefore, attention must be paid to the planning and control of such logistics activities. Effectively improve the success potential of SME entrepreneurs and possess their potential.

1.1 Objective

To study the effect of the characteristics of Small and Medium Enterprises (SMEs) to the purchase order and information system cost

1.2 Research hypothesis

There is the effect of the characteristics of Small and Medium Enterprises (SMEs) to the purchase order and information system cost.

1.3 Expected outcome

To enable SMEs to choose the method that is most useful most suitable and the most economical for sustainable business operations.

1.4 Cost reduction

Cost refers to expenses that expected to occur and cause the business to receive benefits or returns in the form of assets or services. Business costs can be considered separately based on usage for instance, benefits that should be received during a certain period of time. Order processing and information system costs are costs related to the process of managing customer orders. Both communication inside and outside the organization and demand forecasting [3].

1.5 *Order processing and information system costs*

Order processing and information system costs are costs that arise from the order process activities, beginning with the receipt of an order from the customer. Word data management Internal and external communications, purchase order, product distribution Including forecasting future customers' needs [4].

2 Methodology

2.1 *Population*

Population used in the study is Entrepreneurs of small and medium enterprises that export business in Pathum Thani Province. In the total of 24,453 persons.

2.2 *Sample*

Sample group used in the study Because they know the exact population. Therefore calculate the group size samples using the Taro Yamane formula instead of values, using the formula at the 95% confidence level. The 5% tolerance yields the sample size. Therefore, the sample size used in this research Equal to 400 samples.

The questionnaire was using a five-point Likert scale (1 = very negative, 2 = negative, 3 = neutral, 4 = positive, 5 = very positive). The data was analysed using SPSS with descriptive analysis and ANOVA.

3 Result and discussion

3.1 *Result*

The characteristics of the participants are summarized in Table 1. The number of participants of the study was accounted to 400 (N=400) where more than 31.3 percent of the participants has registered capital 1-5 million, 31.1 percent of the participants has registered capital 6-10 million, 17.7 percent of the participants has registered capital 11-20 million, 8.7 percent of the participants has registered 21-30 million , 4.7 percent of the participants has registered capital 31-40 million and 6.4 percent of the participants has registered capital Over 40 million respectively.

Table 1 Characteristics of SMEs

Register Capital	N	%
1-5 million	147	31.3
6-10 million	146	31.1
11-20 million	55	17.7
21-30 million	22	8.7
31- 40 million	10	4.7
Over 40 million	20	6.4
Total	**400**	**100**

3.2 *Hypothesis testing*

The different of Characteristics of SMEs in registered capital affect the purchase order and information system cost.

H_0 : Different registered capital factors do not affect the purchase order and information system cost.

H_1 : Different registered capital factors affect the purchase order and information system cost.

The researcher used one-way analysis of variance (One Way ANOVA) with statistical significance set at the .05. level according to the determination of statistical significance to test differences among groups. In the case that there are differences between groups, the Least Significance Difference (LSD) test statistic will be used to compare the differences between those groups on a pairwise basis. The results of the hypothesis test results are as follows:

Table 2 Statistics comparing differences in opinions regarding the purchase order and information system cost classified by registered capital

registered capital	Mean	SD	F	Sig.
1-5 million	4.231	.697	3.579	.003
6-10 million	4.183	.679		
11-20 million	4.129	.717		
21-30 million	4.228	.594		
31- 40 million	3.833	.936		
Over 40 million	3.722	.889		
Total	4.146	.723		

By comparing differences in opinions regarding the purchase order and information system cost classified by registered capital found that fee Sig. has a value equal to .00, which is less than 0.05, therefore rejected. H_0 and accept H_1 which means different registered capital factors affect the purchase order and information system cost significant level at 0.05.

Due to the differences were found for each group, the researcher therefore tested the differences in each group in pairs using statistical tests. LSD details as shown in the following table.

Table 3 Statistics comparing differences in opinions regarding the purchase order and information system cost classified by registered capital In pairs

registered capital	average	1-5 million	6-10 million	11-20 million	21-30 million	31-40 million	Over 40 million
		4.23	4.18	4 .13	23.4	83.3	72.3
1-5 million	4.23	-	.486	.103	.004	.398*	.509*
6-10 million	4.18		-	.054	-.045	.349*	.460*
11-20 million	4.13			-	-.099	.295	.406*
21-30 million	4.23				-	.394*	.505*
31-40 million	3.83					-	.111
Over 40 million	3.72						-

sign means * note The Statistically significant at the level 0.05

From table 3 Found that SMEs with different registered capital have 7 pairs of opinions regarding the purchase order and information system cost that are significantly different at the level 0.05.

1. SMEs with different registered capital 1-5 million The average opinion about the purchase order and information system cost was higher. SMEs with different registered capital 31-40 million with an average of -.398*.

2. SMEs with different registered capital 1-5 million The average opinion about the purchase order and information system cost was higher. SMEs with different registered capital Over 40 million with an average of .509*.

3. SMEs with different registered capital 6-10 million The average opinion about the purchase order and information system cost is higher than SMEs with different registered capital 31-40 million . with an average of .349*.

4. SMEs with different registered capital 6-10 million The average opinion about the purchase order and information system cost was higher than SMEs with different registered capital Over 40 million . with an average of .460*.

5. SMEs with different registered capital 11-20 million There is an average opinion about the purchase order and information system cost being more than SMEs with different registered capital Over 40 million with an average of .406*.

6. SMEs with different registered capital 21-30 million There is an average opinion about the purchase order and information system cost being 31-40 million more than SMEs with different registered capital. with an average equal to .394*.

7. SMEs with different registered capital 21-30 million There is an average opinion about the purchase order and

information system cost being more than SMEs with different registered capital Over 40 million with an average equal to .505*.

3.3 Conclusion

The characteristics of Small and Medium Enterprises (SMEs) has affected to the purchase order and information system cost. This means most the Small and Medium Enterprises (SMEs) use information systems in the flow of information through electronic processes.

3.4 Discussion

Determining the reduction of operating costs explains the order processing and information system effects of operating costs.

The study found that there is a strong effect of registered capital of SMEs to order processing and operating costs and information system costs. The effect of registered capital of SMEs to order processing and operating costs and information system costs which consistent to the work of Sasitorn Onsanit 's research, analyzing the activities affected to the logistics that reduce the cost of logistics systems [5].

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Design of low-pressure transportable steel tanks for storing hydrogen for an electric tractor

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Keywords: hydrogen, low-pressure storage, pressure vessel, metal hydride.
Abstract: The presented contribution offers a theoretical analysis of the possibilities of implementing hydrogen technologies in agricultural machines and tractors. It discusses in more detail the structural designs and strength calculations of low-pressure transportable steel tanks for hydrogen storage for the ET 3000 electric tractor, in which the accumulators will be replaced by designed metal hydride tanks. The structural design of low-pressure tanks meets the requirements of the STN EN 13322-2 standard, which deals with the technical and structural design of transportable pressure tanks. The design and construction of tanks are key from the point of view of the real implementation of hydrogen technology in a fully functional small tractor for the purpose of its long-term testing.

1 Introduction

Due to the expanding share of hydrogen technologies, research and development of hydrogen storage equipment is also underway. The most widely used hydrogen storage system is based on the high-pressure principle, and from a safety point of view, this type of storage may not always be the most suitable. This type of storage is used, for example, by the New Holland NH2 tractor with a drive based on the principle of fuel cells with a total output of 78 kW, presented in 2009 at the SIMA agri-business show in Paris. Hydrogen weighing 2.4 kg is stored in a pressure tank in the front part of the vehicle and enables the machine to operate for a maximum of 2 hours. The H2 Dual Power model from the same manufacturer from 2020 has 11.5 kg of hydrogen stored in 5 tanks with a pressure of 350 bar located above the driver's cabin. The drive is provided by a modified 4.5 liter diesel engine with 2 operating modes, enabling the combustion of 100% diesel or 30 to 60% hydrogen-diesel mixture. A modified 4.8-liter diesel engine burning a lean mixture of hydrogen (1% H_2 and 99% air) using high-pressure hydrogen storage is also applied in the 2022 JCB Hydrogen tractor.

In the 80s of the 20th century, the first efforts to implement low-pressure hydrogen tanks based on metal hydride in a tractor were recorded. A tractor operated on a farm in Clarsburg, Ontario, Canada, used a modified dual duty gasoline engine. The hydrogen storage system consisted of 11 metal hydride tanks containing a total of 80 kg of metal hydride alloy, while the total maximum amount of stored hydrogen represented 1 kg.

With the gradual development of low-pressure storage of hydrogen in metal alloys, there is a need to design such gas tanks that meet the criteria defined in the currently valid regulations and standards. A characteristic feature of low-pressure hydrogen tanks containing metal hydrides is the need to cool the alloys during the process of hydrogen absorption into the metal alloy structure and to heat the alloys during hydrogen desorption. The article describes the design process of metal hydride hydrogen tanks according to current standards. Metal hydride tanks were designed for the electric mini tractor ET 3000, in which they will replace the accumulators, which are located in two dedicated spaces located under the driver's seat.

For the 1st reserved space, a steel tank was designed according to the valid standard STN EN 13322-2. For the second space, a system of tanks was designed so that they fill the reserved space as efficiently as possible. Designs of cylindrical tanks were made, which would be stored in the first horizontal variant and in the second vertical variant.

The volume of stored hydrogen was also calculated for individual tanks. The structural designs of the tanks were realized in the Solidworks program tool, and the ANSYS Workbench-Static Structural software was used for the strength analysis of the designed tanks [1-13].

2 Design of transport steel containers for an electric tractor

The transport steel tanks for hydrogen storage are designed for the electric small tractor ET 3000, the serial number of which is 3000-4B-002. In the next part of the work, transportable steel tanks for hydrogen storage are designed, which will replace accumulators in the electric mini tractor. The tanks contain Hydralloy C5 powder alloy and from the point of view of location, they are located in two reserved spaces, where the first reserved space has dimensions of 800x250x220 mm and the dimensions of the second reserved space are 530x240x265 mm.

3 Design of the MNTZV-194 tank for the first reserved space

The STN EN 13322-2 standard was used in the design of the tank for the first reserved space. The designed tank is double-shelled and consists of a primary tank, which contains a TiFe-based metal hydride alloy called Hydralloy C5, and a shell that is welded to the primary tank. Between the primary tank and the shell is a gap in which the cooling liquid flows and serves to cool the tank during the process of hydrogen absorption into the metal alloy structure.

3.1 Calculation of the thickness of the cylindrical wall of the primary tank

The thickness of the wall of the cylindrical part must not be less than the minimum calculated thickness of the wall of the cylindrical part *a*, while it is calculated according to the formula:

$$a = \frac{D}{2} \cdot \left(1 - \sqrt{\frac{10 \cdot F \cdot J \cdot Re_V - \sqrt{3} \cdot p_h}{10 \cdot F \cdot J \cdot Re_V}}\right) \quad (1)$$

where: D - outer diameter of the reservoir (mm), F - design stress factor, J - stress reduction factor, Re_v - calculated yield strength (MPa), p_h - maximum test hydraulic pressure above atmospheric (bar).

A value of 194 mm was chosen for the outer diameter of the container D. According to the standard, the design stress factor is F = 0.77 and the stress reduction factor is 1 because there is a butt weld on the tank cap. The calculated yield strength based on the selected material, which is steel 1.4404/AISI 316L is set on a value of 425 MPa according to the standard. The maximum test hydraulic pressure above atmospheric p_h is determined according to the relationship:

$$P_h = p_p \cdot k \quad (2)$$

where: p_p – working pressure and has a value of 30 bar, k – safety coefficient, determined according to the established standard with a value of 1.43.

By substituting into equation (2), it was found that the minimum p_h value is 42.9 bar. A higher value of 47 bar was chosen for the test hydraulic pressure above atmospheric. By substituting the values into equation (1), it was found that the minimum wall thickness is equal to 1 mm.

3.2 Determination of bottoms of designed tank

For closing the vessel, the standard prescribes 2 types of bottoms, namely torispherical and ellipsoidal. During the design, ellipsoidal bottoms were chosen, the shape of which must meet the conditions:

$$H \geq 0{,}19 \cdot D \quad (3)$$
$$h \geq 4 \cdot b \quad (4)$$

where: H – outer height of the arched part of the bottom (mm), h – height of the cylindrical part of the bottom (mm), b – calculated minimum thickness of the cylindrical bottom (mm).

Substituting into equation (3), the value of the outer height of the arched part of the bottom is obtained $H \geq 37.248$ mm, a higher value of 60 mm was chosen for H.

Calculation of the minimum thickness of the cylinder bottom:

$$b = a \cdot C \quad (5)$$

where: C is the shape factor of the arched bottoms, where according to the standard it takes the value of 0.775.

The calculated minimum thickness of the cylinder bottom b has a value of 0.775 mm. After substituting into equation (4), it was found that the minimum height of the cylindrical part is 3.1 mm. The value chosen is: h = 15 mm.

3.3 Minimum wall thickness of the primary reservoir

In addition to the above equations for calculating the minimum wall thickness of the cylindrical shell and the bottom, it must be valid that its value is not less than the value derived from the following relationship:

For $D \geq 150$ mm applies:

$$a = b = \frac{D}{250} + 0{,}7 \quad (6)$$

After substituting the values into equation (6), the value of the thickness of the cylindrical part and the bottoms of the tank is obtained as 1.476 mm. The standard further describes that the absolute minimum thickness of the tank wall for diameters greater than 150 mm is 1.5 mm. The selected value of the thickness of the cylindrical part of the primary tank is 4.5 mm and the selected thickness of the bottoms of the tank is 5.5 mm.

3.4 Design of the tank shell

The same procedure as for the primary tank, which is described above (see chapter 3.1), will be used for the design of the shell. Equation (1) is used for the calculation, in which only the diameter of the cylindrical part D, which has a value of 219 mm, and the test hydraulic pressure p_h, which has a value of 5 bar, are changed. The calculation determines the minimum thickness of the cylindrical wall of the case a = 0.144 mm. The minimum wall thickness of the tank shell is determined in the same way as for the primary tank using relation (6) and the chosen value of the thickness of the cylindrical part of the shell is 2 mm.

In Table 1 there is a recapitulation of all selected dimensions for the designed tank.

Table 1 Selected dimensions of the metal hydride reservoir

	a (mm)	*b* (mm)	*a₂* (mm)	*h* (mm)	*H* (mm)
Selected dimensions	4,5	5,5	2	15	60

The next step of the work is the creation of a simulation model for the strength calculation of the designed tank.

3.5 Strength analysis of the designed tank

The ANSYS Workbench – Static Structural software was used for the strength analysis of the metal hydride tank MNTZV-194. To calculate the strength analysis, it is necessary to set the boundary conditions. Inside the tank there is a metal hydride, in boundary conditions the function of hydrostatic pressure was used for the metal hydride. The density value was set to 7,000 kg·m^{-3}. There is water with a density of 1,000 kg·m^{-3} between the cylindrical part of the primary tank and the cylindrical part of the shell. The value of the maximum test hydraulic pressure on the inner walls of the primary vessel is defined as 4.7 MPa. Earth's gravity was set as another boundary condition. The last boundary condition was the bond setting. Cylindrical bonding was used on the surfaces between the elliptical bottoms and the cylindrical part of the shell.

3.6 Results of the strength analysis of the designed tank

From the strength analysis, it was found that the maximum stress according to the von Mises theory takes on values of around 110 MPa, which is significantly lower than the value of the yield strength of the selected material determined by the manufacturer, which is 210 MPa. The result of the tension is shown in Figure 1. The total deformation on the tank according to the simulation represents a value of 0.07 mm and is shown in Figure 2.

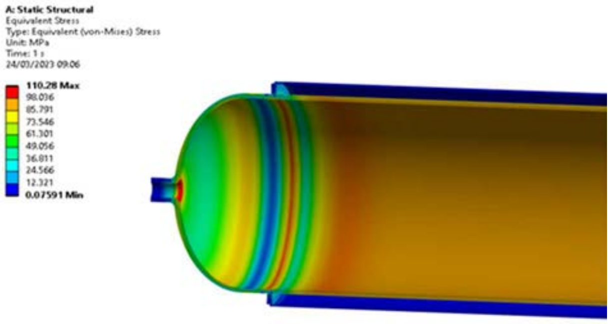

Figure 1 Field of reduced stress according to von Mises theory on the designed tank

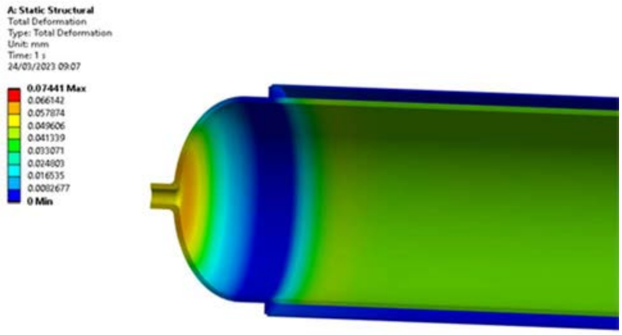

Figure 2 Formed deformations on the tank

Based on the strength analysis, it was found that the tank complies with the operating parameters.

3.7 Calculation of the amount of stored hydrogen in the designed tank

In order to determine the amount of hydrogen stored in the reservoir, it is necessary to determine the individual parameters of the selected metal hydride Hydralloy C5: The bulk density of Hydralloy C5 is ρ_{MH} = 3500 kg·m^{-3}, the hydrogen storage capacity α_{MH} = 1.5 was subtracted from the PCI curve, at working pressure 30 bar and absorption temperature 50 °C, storage volume V = 1.889·10^{-2} m^3 and hydrogen density ρ_{H2} = 0.0899 kg·m^{-3}.

The weight of the alloy m_{MH} is determined from the equation:

$$m_{MH} = \rho_{MH} \cdot V = 64{,}8\ kg \tag{7}$$

The mass of stored hydrogen m_{H2} is calculated according to the formula:

$$m_{H2} = \frac{\alpha_{MH} \cdot m_{MH}}{100} = 0{,}972\ kg \tag{8}$$

Subsequently, the volume of stored hydrogen V_{stored} was determined:

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$$V_{stored} = \frac{m_{H2}}{\rho_{H2}} = 10{,}8\ m^3 \qquad (9)$$

4 Design of a storage system for the second reserved space

In this part, the design of the tank system for the 2nd reserved space of the electric small tractor ET 3000 with dimensions of 530x240x265 mm will be presented in more detail.

In this design, it was considered that the cylindrical tanks in the 2nd space of the ET 3000 electric tractor would occupy as much space as possible. Two variants were made, specifically in the first variant, the tanks would be stored horizontally, and in the second variant they would be stored vertically. Three models were made for each variant, in which all parameters remained the same, only the thickness of the wall was changed, and thus the inner diameter of the tank was reduced. In both the first and second variants, the wall thicknesses for the three models were as follows: 1.5 mm, 2 mm and 2.5 mm. The radii of the rounding on the neck are 1 mm on the outside and 0.5 mm on the inside. In the first variant, the tank diameter is 48 mm and the length is 480 mm. In the second variant, the diameter of the tank is 50 mm and the height is 170 mm. The structural design includes only the cylindrical part and the bottoms of the tanks, while one bottom has a hydrogen inlet.

During the design, it was considered that the tanks would be placed in a corrosion-resistant steel container, which would be placed in the 2nd space, and the entire space in the container would be filled with water, which would ensure full-surface cooling of the reservoirs. In the first length variant, 9 tanks would be placed in the corrosion-resistant steel container - 3 rows and 3 tanks are stored in each row. For the second vertical variant, three rows were considered and there would be 7 tanks in each row, so a total of 21 tanks. Both horizontal and vertical tanks variants were strength analyzed for different thicknesses like the tank in the previous chapter. The result of the strength analysis of the tank of one of the variants is shown in Figure 3 and Figure 4.

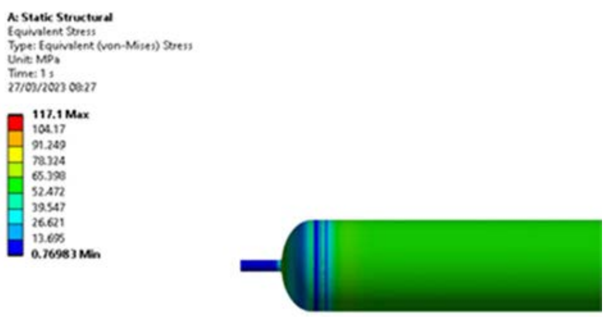

Figure 3 Field of reduced stress for 1st horizontal variant with 1.5 mm wall thickness

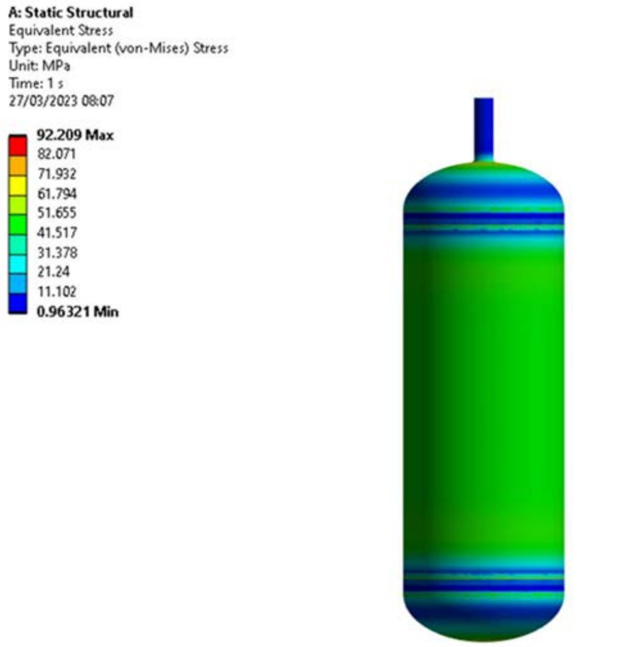

Figure 4 Field of reduced stress for 2nd variant in vertical with a wall thickness of 2 mm

The results of all tank strength analyzes are shown in Table 2 and Table 3.

Table 2 Results of the strength analysis of the designed tanks of the first horizontal variant

	1st horizontal variant		
Wall thickness (mm)	1.5	2	2.5
Maximum stress (MPa)	117.1	85.71	92.02
Maximum deformation (mm)	0.013	0.0096	0.0072
Volume of the tank (m^3)	$7.12\cdot10^{-4}$	$6.8\cdot10^{-4}$	$6.48\cdot10^{-4}$
Weight of the metalhydride (kg)	2.44	2.33	2.22
Weight of stored hydrogen (kg)	0.037	0.035	0.033
Volume of stored hydrogen for 1 tank (m^3)	0.4	0.38	0.36

Table 3 Results of the strength analysis of the design tanks of the second vertical variant

	2nd horizontal variant		
Wall thickness (mm)	1.5	2	2.5
Maximum stress (MPa)	138.64	92.21	107.42
Maximum deformation (mm)	0.042	0.011	0.0083
Volume of the tank (m^3)	$2.39 \cdot 10^{-4}$	$2.28 \cdot 10^{-4}$	$2.17 \cdot 10^{-4}$
Weight of the metalhydride (kg)	0.82	0.78	0.74
Weight of stored hydrogen (kg)	0.0123	0.0117	0.0111
Volume of stored hydrogen for 1 tank (m^3)	0.14	0.13	0.12

5 Discussion

The MNTZV-194 tank designed according to the STN EN 13322-2 standard for the first reserved space of a small tractor, based on strength calculations, meets the operational parameters and is suitable for use from the point of view of structural strength.

For the second reserved space, in terms of operating parameters, it is most suitable to use a tank with a wall thickness of 2 mm with length storage - 1st variant. This tank has the lowest tension according to the von Mises theory and the total deformations do not exceed the value of 0.01 mm. It is also more advantageous from an economic point of view, because if the 2nd vertical variant was chosen, then the proposal contains 21 tanks, while the height of 1 tank is only 180 mm. The total cost of production and assembly of a given design is greater. The last decisive criterion is the amount of stored hydrogen in the system, which was calculated on the basis of formulas (7) to (9), considering the same conditions as when calculating the stored hydrogen for MNTZV-194 (see chapter 3.7). When comparing tanks with the same wall thickness, more hydrogen is stored in the first variant. Of course, for the lowest wall thickness of 1.5 mm, the volume of stored hydrogen is the largest, but such a tank has a much higher stress.

6 Conclusion

In the paper, efficient hydrogen storage systems in a metal alloy structure were proposed for the ET3000 small tractor. The first part was the design of the metal hydride tank according to the valid standard STN EN 13322-2 and then the verification of its structural strength. Based on strength calculations, it was found that the tank meets the operating parameters. The next step in the design of this tank would be the investigation of the generated temperature fields and the subsequent design of an effective method of cooling. For example, a suitable passive heat transfer intensifier would be inserted into the tank, which serves to remove the generated heat from the core of the tank to the inner wall of the primary tank during the hydrogen absorption process.

In the second part, the main task was to design an effective system of cylindrical tanks that would fill the second reserved space of the small tractor with dimensions of 530x240x265mm as efficiently as possible, where storage of the horizontal and vertical were considered. On the basis of strength calculations and the amount of stored hydrogen, it was found that in this case it is most appropriate to use the tank of the first vertical variant with a wall thickness of 2 mm.

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Methodical approaches to valuation of intangible assets

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Keywords: intangible assets, valuation, international accounting standards.
Abstract: Intangible assets in the activities of business entities can constitute a significant part of assets. Their valuation can be done in several ways, which are fundamentally different. Literature offers several methods for valuing intangible assets, which are based on three basic approaches. Each of them captures the value of the property based on different specific characteristics. The issue of intangible assets is also addressed by international accounting standards, the task of which is to guide the accounting and reporting of this type of assets so that the financial statements provide correct and complete information that is comparable on a global basis.

1 Introduction

The main motive of every business entity is to ensure profit from its business activity.

In addition to the primary management activity to ensure the entity's prosperity, it is necessary for the entity to devote equal care to economics, accounting and reporting.

Every entity needs assets, which is a necessary prerequisite for carrying out business activities. From an accounting, but also from an economic point of view, assets are divided into tangible and intangible. In many cases, intangible assets have a high value and sometimes cannot even exist without a tangible component. When creating the price of intangible assets, we can encounter significant specific factors that do not appear in tangible assets. The valuation of intangible assets is a very difficult task due to the nature of the assets, as it is difficult to determine the boundary between intellectual and other forms of capital. One of the purposes of the article is to summarize the current theoretical state in this area, to characterize the basic methods and to determine their main advantages and disadvantages.

International accounting standards also deal with the issue of intangible assets. This article presents the main aspects of the issue of intangible assets as defined and presented in IAS 38 Intangible Assets. It is a category of assets that has recently seen greater development and dynamics in terms of their appearance in the structure of long-term assets and in the actual financial statements of Slovak entities

2 Literature review - approaches in valuation of intangible assets

It is common to use several methods for valuing intangible assets, which are presented in both domestic and foreign literature. Some of them are devoted to definition only at the theoretical level and some in combination for their practical application in the business field. There are also methods that are based on financial theory. Each of them has its advantages and disadvantages, but none is able to satisfy all requirements [1]. The valuation of intellectual property is a very difficult task due to the nature of the property, because it is difficult to determine the boundary between intellectual and other forms of capital. Another drawback of intellectual property valuation methods is that current academic publications often focus on current trends and ignore aspects of already existing classical methods. Therefore, the current methods are mostly complicated theoretical proposals, their usability in practice is limited, which slows down the development of an unified way of measuring intellectual property in entities both at the national and international level. Property valuation experts mostly agree on the classic division of methods into three basic approaches:

- Cost approach.
- Income approach.
- Comparative approach.

The mentioned approaches appear to be the most suitable for the comparative, economic and physical characteristics of the entity's assets [2].

Cost approach

The cost approach is the simplest way to value intangible assets. The methods of this approach try to capture the value of the property based on an estimate of the costs associated with its development. It means a direct relationship between costs and the value of intangible assets. The result is not the value of intangible assets. From the perspective of the market, or the buyer, the result does not reflect the potential benefit of the given asset [3]. This approach is based on the principle of economic substitution, i.e. the idea that the interested party is not willing to pay more for an intangible asset than it would pay in economic costs for the creation of an intangible asset of comparable utility. Appraisal by the cost method is the determination of the value of the input of human labor, material and creative energy, necessary for building or acquiring similar assets in current economic conditions and the current state of the given industry [4]. This approach represents the costs associated with the direct reproduction of the property or the costs associated with the replacement of the valued property, takes into account functional deficiency and economic, or more precisely moral obsolescence [5]. Intangibles are a diverse group, and a wide range of costs are associated with them. Intangible assets are primarily:

- Costs of research, development, testing (for technical solutions).
- Costs of consumer surveys, advertising campaigns, administration associated with introduction to the market (for trademarks).
- Costs related to legal protection [4].

Income approach

Income approach is the most widely used approach to value intangible assets. It is based on the principle of economic expectation, i.e. the idea that the interested party is not willing to pay more for an intangible asset than the current value of the expected income from the use of the asset at a degree of risk at the level of a comparable investment. The income approach represents the second generation of intellectual property valuation methods. It is based on the property's ability to generate cash flow. While the comparative approach has its limitations and the cost approach is applicable only in special cases, income approach methods are generally applicable to most intangible asset valuation situations. This approach [6] is based on discounted cash flows and defines the value of the asset as the present value of the net expected income to be achieved during its economic life. When calculating the value of the asset, it is based on the future income related to the business, then their current value is determined and the part of this value that is related to intellectual property is verified. The costs associated with the operation of the asset must also be separated from this potential gross income. When determining the value of an asset, the income approach focuses on the net cash flow derived from the use of the asset, the duration of the source of income and the discount rate (inflation, risk, interest rates) [7].

The most widespread method for valuation of intangible assets, especially intellectual property rights, is the license analogy method. This method is based on the consideration that the value of the intangible asset is equal to the price that would most likely be paid on the market for agreeing to use a similar or identical solution, or for its transfer. The rights to use are provided in the form of a license or similar contract. A license fee is paid for the right to use them [8].

Comparative approach

Comparative approach methods of intellectual property valuation determine the value of assets by studying transactions with assets that are similar to the one being valued under similar circumstances. The price of the comparable asset is subsequently adjusted for characteristics that are different compared to the characteristics of the relevant asset (such as date of sale, location, type, age and technical condition, and likely future use). Based on the application of the average price, a value estimate is obtained based on the principle of a comparative approach. Considering the determination of the value of the property based on comparable transactions, a high level of awareness is required [9]. Compared are:

- Economic characteristics.
- Technological characteristics.
- Functional characteristics.
- Economy sector.
- Economic conditions on the given market at the time of the compared transaction.
- The existence of above-standard financial conditions of the transaction [6].

In order to be able to use this method, it is necessary to have a given market, a sufficient number of traded goods on the market and the availability of the necessary information. The procedure of this method consists of several steps:

- Finding a suitable market, timeliness of accounting.
- Obtaining all available information on transactions with a comparable good.
- Analyzing and checking the timeliness of information obtained.
- Selection of comparing units and their analysis.
- Comparison of selected units with the appraised property according to certain characteristics.
- Summarizing the obtained data into one data or within a certain range [2].

The advantage of this approach is that it can be applied to a wide range of intangible assets. Information and market transactions data can be very useful in the analysis and valuation of intellectual property, but are rarely comprehensive enough to form the basis of a satisfactory valuation of the property [4].

2.1 Advantages and disadvantages of individual approaches

Each of the above mentioned intangible asset valuation approaches has its application, often as a supporting method. Table 1 contains the most significant advantages and disadvantages of individual approaches and methods.

Table 1 Advantages and disadvantages of individual approaches

Approach	Advantages	Disadvantages
Cost	It is based on the principle of economic substitution. Simple calculation. It is suitable in cases where the benefit from an intangible asset is not clear. The amount of an intangible asset appears in the accounting records as soon as it is created.	These methods are not able to work out the market value of an intangible asset, because there is no direct relationship between the value of an intangible asset and the costs necessary to create it. When calculating, this approach does not take into account the future income that the intangible asset is capable of generating. The result does not reflect the potential benefit of the given asset. Determining the cost of "creating" an intangible asset is difficult, because it is necessary to carry out a detailed analysis of the subject of the valuation (basic, technical parameters).
Income	It is based on the principle of economic expectation. Income approach methods are generally applicable to most types of intangible assets. The basic method of valuation of intellectual property rights, which are tradable in the form of license agreements. Relatively simple calculation The necessary data are in most cases available from the financial records of entities. The related cash flow is predictable.	The disadvantage of the methods is that they are based on the assumptions of future development, which is always associated with a certain degree of risk. It is necessary to predict not only the future cash flow, but also to estimate the discount rate. The non-market method (valuation according to the law) will never calculate the market value of the asset, because it does not consider the nature of the intangible asset and their difference.
Comparative	It is based on the principle of balance. Relatively unambiguous valuation approach. It can serve as a check on the results of other approaches. Can be applicable to a wide range of intangible assets.	Limited market in the area of trading with intangible goods. A high level of market awareness is required. The necessary resources and information for the valuation are not publicly available or are incomplete. The uniqueness of intangible assets complicates the comparison.

2.2 Determination of the general value of intangible assets in the Slovak Republic

The calculation of the general value of intangible assets in the Slovak Republic is governed by Decree no. 492/2004 Coll. Ministry of Justice of the Slovak Republic, which establishes methods and procedures for determining the general value of assets. The general value of the intangible results of research and similar activities and the general value of assessable rights shall be determined in accordance with the aforementioned decree:

a) by the license analogy method in case of licenses, patents, trademarks and other tradable parts of intangible assets, or
b) by the method of capitalization of exhaustible resources; the basis is the determination of the length of the period in years during which the intangible asset will be used; calculation of the volume of exhaustible resources, which are created by the use of valued intangible assets; determination of the share that falls to the valued intangible assets of the company from the generated exhaustible resources, by relationship (1), (2):

$$V\check{S}H_{NIM} = SH_{OZ} * p_{NIM} \quad [€] \qquad (1)$$

where
$V\check{S}H_{NIM}$ - general value of the company's intangible assets.

$$SH_{OZ} = \sum_{t=1}^{n} \frac{OZ_t}{(1+i)^t} \quad [€] \qquad (2)$$

where
n - number of years of use of intangible assets of the company [year],

SH_{OZ} - current value of future exhaustible resources as of the date of preparation of the expert opinion [€],

p_{NIM} - the percentage by which the valued intangible asset participates in the creation of exhaustible resources, which is entered into the calculation in decimal form [%/100],

i - capitalization rate in percentages calculated according to Annex no. 1 of part 2, which is inserted into the calculation in decimal form [%/100] [10].

3 Results and discussion - intangible assets from the International Accounting Standards point of view

Intangible assets are covered by the IAS 38 standard, which sets the rules for the accounting display, valuation and disclosure of intangible assets. This standard requires an entity to recognize an intangible asset if, and only if, specified standard criteria are met, namely:

- The scope of the standard.
- The recognition and valuation of intangible assets.
- Methods of acquisition of intangible assets.
- Useful life.
- Retirement and disposal of intangible assets and their disclosure.

Scope of the standard Intangible assets

In the introductory part, the standard defines the scope, because there are a number of intangible assets falling under the diction of other standards that regulate these other intangible assets. According to the standard IAS 38 **intangible asset** is an identifiable non-monetary asset without physical substance. The standard emphasizes the recognition of an intangible asset and that it is identifiable. It is identifiable if it either:

- Is separable, i.e. is capable of being separated or divided from the entity and sold, transferred, licensed, rented or exchanged, either individually or together with a related contract, identifiable asset or liability.
- Or arises from contractual or other legal rights, regardless of whether those rights are transferable or separable from the entity or from other rights and obligations.

An entity controls an asset if the entity has the power to obtain the future economic benefits flowing from the underlying resource and to restrict the access of others to those benefits. The capacity of an entity to control the future economic benefits from an intangible asset would normally stem from legal rights

The future economic benefits flowing from an intangible asset may include revenue from the sale of products or services, cost savings, or other benefits resulting from the use of the asset by the entity. This is how the standard defines future economic benefit for intangible assets.

Recognition and valuation of intangible assets

An intangible asset shall be recognized if, and only if:

- It is probable that the expected future economic benefits that are attributable to the asset will flow to the entity; and
- It is possible to reliably value the costs associated with the acquisition of the intangible asset.

The standard directly lists examples of intangible assets that do not meet the criteria for the recognition of intangible assets, namely:

- Establishment expenses.
- Expenses for retraining employees.
- Advertising and promotion expenses.
- Expenses for relocation or reorganization of a part or the whole company.

The main reason for not recognizing these assets is that it is very difficult to assign such expenses directly to a specific intangible asset and distinguish them from the expenses of developing the business as a whole. Therefore, subsequent expenses incurred after the inclusion of an intangible asset in the entity's assets, as well as intangible assets created by the entity's own activity, are rarely reflected in its accounting value. The standard states that subsequent expenses on brands, mastheads, publishing titles, customer lists, and items similar in substance—whether externally purchased or internally generated—are always included in the income statement in the period in which they are incurred. These expenses cannot be distinguished from the expenses of developing the business as a whole.

Initial valuation of intangible assets

An intangible asset shall be valued initially at cost. The standard defines the following options for acquiring intangible assets:

- Separate acquisition of intangible assets.
- Acquisition of intangible assets as part of a business combination.
- Acquisition of intangible assets by way of a government grant.
- Internally generated intangible assets.

Separate acquisition of intangible assets

The cost of a separately acquired intangible asset comprises:

- Its purchase price, including import duties and non-refundable purchase taxes, after deducting trade discounts and rebates.
- Any directly attributable cost of preparing the asset for its intended use.

Examples of directly attributable costs are:

- Costs of employee benefits arising directly from bringing the asset to its working condition.
- Professional fees arising directly from bringing the asset to its working condition.
- Costs of testing whether the asset is functioning properly.

Recognition of costs in the carrying amount of an intangible asset ceases when the asset is in the condition necessary for it to be capable of operating in the intended manner. The following costs are not included in the cost price of an asset.

Acquisition of intangible assets as part of a business combination

Regarding the issue of the acquisition of intangible assets as part of a business combination, the standard briefly states that if an intangible asset is acquired in a business combination, the cost of that intangible asset is its fair value at the acquisition date The main attributes of recognition of an intangible asset during a business combination at the acquirer are the reliability of determining the fair value of the asset - the existence of an active market, the possibility of determining the useful life of the acquired asset and control of the asset.

Acquisition of intangible assets by way of a government grant

In case the entity acquires an intangible asset in the form of a government grant, the standard refers to the solution according to the Government grant standard. These are the situations where an intangible asset is acquired free of charge, or for nominal consideration, by way of a government grant. It may be e.g. licenses to operate radio or television stations, licenses or quotas for the import of certain commodities, import licenses or quotas or rights to access other restricted resources, etc. In case of small and medium-sized entities, it may be the allocation of production quotas in agriculture or the allocation of emission quotas in manufacture. The synergy with the above-mentioned standard lies in the fact that according to its wording, the entity is allowed to recognize assets and, at the same time, the received grant during the initial recognition at fair value. The standard also allows an alternative solution, if an entity does not recognize the asset initially at fair value, or, if there is no functional active market, the entity recognizes the intangible assets acquired at nominal value increased by expenses directly attributable to the preparing the asset for its intended use.

Internally generated intangible assets

Internally generated intangible assets are regulated in great detail in the Intangible Assets standard. The standard resolves whether the entity can even consider certain items internally generated as intangible assets, or whether it is an expense of the given period.

The problem is to determine from which moment it is possible to recognize an intangible asset in the balance sheet with sufficient certainty. This is primarily the moment when the entity can demonstrate with sufficient certainty that an intangible asset will generate future economic benefit.

An entity can implement various projects for which it spends considerable resources. During the development of such projects, the entity cannot declare their success, or meet the basic definition of assets. Therefore, the standard solves the basic question of when to activate the spent funds into assets. Whether it is right from the start of the project or only when certain prerequisites are met.

Another issue related to certain intangibles, such as trademarks, is whether certain costs incurred are clearly related to the development of the trademark as such, or were incurred generally to support the entity's reputation. As the answers to these questions are not clear, the International Accounting Standards Board chose the most cautious solution for certain items and prohibited their activation. The standard recognizes two basic categories of assets created internally, namely the research phase and the development phase.

In the research phase of an internal project, an entity cannot demonstrate that an intangible asset exists that will generate probable future economic benefits. Therefore, ***research costs are recognized as costs*** when incurred. The standard states that an intangible asset arising ***from the development phase of an internal project*** shall be recognized if, and only if, an entity can demonstrate all of the following:

- The technical feasibility.
- Its intention to complete it and sell it.
- Its ability to use or sell.
- The *existence of the market.*
- The availability of resources.
- The ability of reliable valuation.

If at least one of these criteria is not met, the entity cannot capitalize the incurred development costs.

Subsequent costs related to an intangible asset that has already been recognized in the accounting entity's balance sheet are considered technical appreciation in terms of the standard, provided that they increase the economic benefit derived from the asset that it is reliably valued and is attributable to the given asset.

The useful life of an intangible asset, its retirement and disposal

An entity assesses whether the useful life of the given intangible asset is finite or indeterminate. An intangible asset with a finite useful life is amortized, so the entity determines the useful life and the depreciation method. An entity begins to amortize an intangible asset the moment it begins to use it. The amortization method used shall reflect the pattern in which the asset’s future economic benefits are expected to be consumed by the entity. The standard lists the straight-line method, the diminishing balance method and the units of production method. The method used is selected on the basis of the expected pattern of consumption of the expected future economic benefits embodied in the asset and is applied consistently from period to period. The maximum limit of applicability is not set. This is determined by the entity itself. Amortization of intangible assets is the same as depreciation of tangible assets.

If an intangible asset has an indefinite useful life, it may not be amortized and is tested (once a year) for impairment in accordance with standard 26 Impairment of non-financial assets. When determining the useful life, the entity must consider many economic and legal factors, which are mentioned in the standard in this regard.

The entity derecognizes an intangible asset from the balance sheet if:

- Is discarded, e.g. due to sale or entity ceases to use it and recognize its residual value as expense.
- No future economic benefits are expected from its use or disposal.

Disclosure of Intangible Assets

The standard sets strict criteria for the disclosure of intangible assets in the notes to the financial statements. It requires to disclosure the following for each class of intangible assets, distinguishing between internally generated intangible assets and other intangible assets:

a) whether the useful lives are indefinite or finite,
b) the amortization methods used for intangible assets with finite useful lives,
c) gross carrying amount and any accumulated amortization at the beginning and end of the period,
d) a reconciliation of the carrying amount at the beginning and end of the period

The following is published:

a) for an intangible asset assessed as having an indefinite useful life, the carrying amount of that asset and the reasons supporting the assessment of an indefinite useful life,
b) a description, the carrying amount and remaining amortization period of any individual intangible asset that is material to the entity’s financial statements,
c) for intangible assets acquired by way of a government grant and initially recognized at fair value:
   - The fair value initially recognized for these assets.
   - Their carrying amount.
   - Whether they are valued after recognition under the cost model or the revaluation model.

This standard requires high professionalism of the compiler of notes to the financial statements, because notes are the most important element of the presentation of the financial statements, which serve all users of the given statement to create a comprehensive picture of the given entity.

4 Conclusion

Approaches to the valuation of intangible assets are not uniform. Each was developed for certain requirements and has a diverse view of the issue, however, none of them is universal.

The cost approach assumes that an intangible asset can be valued based on the costs that have been invested in it, converted to a present value. The problem with this method can be the fact that the value to the owner of the intangible asset can be much higher than the value that we calculate using past costs.

In practice, the income approach is the most used. It is based on the consideration of the future benefit that the given intangible asset will bring us.

Using the comparative approach, the value of an intangible asset is determined based on a comparison of sales of the same or closely related assets in the market. In practice, however, it is very difficult to find this kind of information, because it rarely happens that intangible assets are sold separately, usually the entity is sold as a whole with all the intangible assets it owns.

The basic feature of valuation of intangible assets is a high degree of subjectivity reflected in

individual methods into many valuation steps. There is no uniform procedure according to which we could proceed and reach a definite conclusion. The article contains a description of the basic approaches to valuation of intangible assets and points out their advantages and disadvantages.

Intangible assets are also covered by the International Accounting Standards, which primarily serve to harmonize the content of financial statements in different countries. Their goal is to achieve a situation where the same transactions are reflected in the financial statements of different entities in the same way, regardless of the state in which the financial statements are drawn up. They thus provide investors with enough reliable data.

According to standard 38, an acquired asset is recognized if the future economic benefit corresponding to the asset is probable and the cost of the asset can be reliably estimated. However, there is a difference in the standards dealing with the reporting of intangible assets created by own activities, namely in the acquisition prices associated with their creation. These are divided into research and development phases. The research phase consists of activities such as acquiring new knowledge, evaluating the results of research, searching for alternative materials, and the like. In the research phase of an internal project, the entity is not able to prove the existence of an intangible asset that is likely to bring future economic benefit yet. In the development phase, the completion of the internally generated asset has not yet been completed, but the company can already document its existence. Acquisition prices of internally generated intangible assets that are in the research phase are always recognized as costs. However, the acquisition prices of such assets in the development phase may enter into the value of the asset, if the conditions required by standard 38 are met and proven by the entity. It means that standard 38 allows, under certain conditions, the capitalization of acquisition prices that are included in the development phase.

An intangible asset recognized by an entity can be registered as an intangible asset with a finite or indefinite useful life. Intangible assets with a finite useful life are amortized. Intangible assets with an indefinite useful life are not amortized, however, must be tested for impairment at each balance sheet date.

The accounting entity derecognizes an intangible asset from the balance sheet if it is retired or ceases to be used and no future economic benefits are expected from its use or retirement.

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Drivers of intangible assets accumulation as a prerequisite for Industry 4.0

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Keywords: Industry 4.0, intangible assets, research and development, human capital, global value chains.
Abstract: Industrial revolutions are causing unprecedented changes in the country's economy. These changes are driven by new technologies and innovations. This is primarily based on the growing importance of intangible assets. These are the main characteristics of the ongoing industrial revolution. In the absence of a precise definition and indicators quantifying Industry 4.0, intangible assets are presumed to be the common basis of determinants of Industry 4.0. This paper presents the theoretical basis for determining the Industrial Revolution. Comprehensively describes the determinants of the accumulation of intangible assets. Implementing a panel regression technique with random effects shows the results. We identify the factors unlocking the accumulation of intangible assets. This is primarily in the area of government direct and indirect support for investment in R&D and other innovation assets. Also, it is about creating the environment to encourage private investment in innovation assets, intangible ICT assets and economic competencies.

1 Introduction and theoretical background

1.1 Industrial revolution in history

The first revolution with the industrial label is dated to the period 1760 to 1820. At that time, there was a shift from manual production to machine production, through the use of water and steam power. The second revolution, also known as the technological revolution (1870-1914). It is characterized by productivity growth and as a period of great economic growth. A major milestone was the invention of electricity, which provided the electrification of factories and the operation of the modern production line. Other benefits of the revolution were development of the international specialization of labour, the extensive development of the railway network and the development of the telegraph. This allowed for a faster flow of information, goods and peoples. However, a negative phenomenon of such rapid changes was the increase in unemployment, which was the result of the gradual replacement of labour activities by machines, which had previously been carried out by man [1].

The third is the digital revolution, otherwise known as the data revolution, which is being implemented to a greater extent and in a different form today. Significant advances in information and communication technology (ICT) and computing are occurring [2]. There is a massive use of computer and communication technologies in manufacturing processes. Thus, machines have started replacing the need for human power. At the same time, there is a decline in industrialization compared to previous revolutions and the emergence of services.

The fourth industrial revolution is referred to as "Industry 4.0". It was introduced in 2012, but only came to the attention of the general public in 2016 through the World Economic Forum in Davos. Industry 4.0 was initially defined as the German Federal Republic's strategy for the computerisation of production under the acronym "Industrie 4.0". The introduction of this initiative was mainly due to the decline in industrial production and productivity, paradoxically in the most industrially developed countries. The latter expect it to increase global competitiveness, especially in relation to the so-called emerging economies. The main objective of this concept was to help rebuild and increase the performance of the European Union's industry, i.e. 'reindustrialisation', building on the EU's industrial tradition and its new innovative potential [3]. The validity of this initiative for EU industrial policy is also confirmed by the European Commission in its 2012 strategy paper [4].

1.2 Industry 4.0

It is important to note that more than a hundred years passed between the first and second industrial revolutions and only thirty years between the third and the present revolution. We are already seeing rapid progress more or less online. The assumption is that this trend will peak within the next decade. The current setting of technology use in everyday life is a dramatic step in society's progress and is unprecedented in all of history. It is now essential to understand Industry 4.0 in a global context, as this transformation will be as fundamental to humanity in terms of scale, scope and complexity as no other technological change in history [5].

Professor Schwab [6] confirms that a range of new technologies will constitute an industrial revolution. The merging of the physical and the intangible, i.e. the digital world, will affect all disciplines of the economy and industry. The current industrial revolution is the only one among the three previous revolutions that represents a planned concept that is stimulated by the state. The main objective is the development of industrial production. Industry is a crucial sector within the economy, as its decline, development or modernisation affects the direction of the whole economy and other specific sectors of the economy such as trade, transport, and others [7].

Industry 4.0 also includes the integration of business partners and customers around the world. Its expected benefits are highly efficient manufactures that are coordinated in real time. This lead to the emergence of new services and business models. There is a consensus in the professional, not just academic, community on the defining manifestations and trends of the fourth-generation industrial revolution. These include new materials, the use of 'big data', the Internet of Things and the Internet of Services, artificial intelligence, sensors and microchips, cyber-physical solutions and new systems, new technologies and innovations, automation and autonomous production, robots, 'clouding', 3D printers, virtual and augmented reality, and so on [8].

The use of next generation technologies is currently at an early stage and we only know with certainty the theoretical potential they can achieve when fully exploited. According to [7] in terms of the so-called *Amara's Law*, we tend to overestimate the impact of new technology in the short term and underestimate it in the long term. Nevertheless, it is difficult to underestimate the future global impact of Industry 4.0, which will occur in most areas of business, socio-economic, tax, consumer behaviour, employment, education and other areas [9]. From our perspective, an important complex macroeconomic aspect that stakeholders need to prepare for is the question of how to ensure attractiveness and competitiveness for new investments.

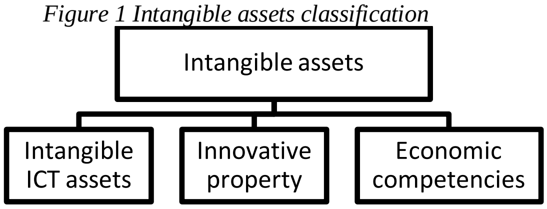
1.3 Accumulation of intangible assets

Recent decades have seen a gradual shift away from the view that a firm's competitive advantage is primarily based on size and strength, towards the view that it is based on intangible assets (intangibles). This shift and the existence of such a view is at the core of the evolutionary theory of the firm according to [10]. The firm is viewed as a "*social community*" whose productive knowledge defines comparative advantage. This theory is based on the principle of differential capabilities and the organizational structure of firms, which are defined by the level of knowledge. A fundamental characteristic of this knowledge is that it is not transferable between different enterprises. [11] presents that it is the distribution of knowledge in the economy that influences the heterogeneity of economic behaviour and governs the way in which competition is conducted. This distribution of knowledge is realized in the form of intangibles [12]. The important role of intangibles in companies was already realized at the beginning of the last century. Professor Veblén [13] argues that the essential basis of an industrial enterprise is its intangibles and the process of value creation in firms. This is largely created and supported by intangibles. The position of intangibles in capitalism is theoretically complemented by [14].

A comprehensive theoretical and methodological insight into intangible was laid down by the works of [6,15], which have established a stream of literature highlighting the role of intangibles and also provide an extensive analytical summary of this area of research. This has been followed by the development of multiple streams of literature addressing the impacts and effects of intangibles [16].

This form of capital, is an increasingly common form of corporate investment and a key contributor to growth in advanced economies. According to the [17], intangibles do not have a physical form and include the following assets shown in Figure 1.

Figure 1 Intangible assets classification



Source: own elaboration based on Corrado et al. 2010

Accurately quantifying the accumulation of intangibles is not at all straightforward, as is the case, for example, with tangible or financial assets, the price of which is determined by trading in the market. In the case of intangibles, the vast majority are accumulated by enterprises through internal research and development. The components of intangibles also include human capital and organisational knowledge, which are difficult to quantify as they are specific assets for a particular enterprise or type of enterprise. Therefore, the most common data source, the National Accounts, only report assets that have a certain market capitalisation, or assets that are derived from its costs. The industrial revolution and the development of ICT are causing the accumulation of assets to shift to intangibles. Currently, the rapid rate of accumulation of intangibles is rapidly moving away from the volume of accumulation of tangibles [18].

According to [15], the accumulation of intangibles is identified as one of the main determinants of innovation and growth. This assumption is already confirmed by the Endogenous Economic Growth Models, which emphasized knowledge and skills as the main determinants of economic growth. They also include the assumption of spillovers, which in the context of knowledge and skills generate sustained economic growth [19,20]. It is now evident that the accumulation of intangibles helps to build knowledge economies. The area of quantifying intangibles is relatively complex, as it is difficult to correctly determine what else can be considered as an investment in intangibles. The acquisition of any intangibles takes only two forms. Either it is acquired by acquisition, i.e. by purchase from other entities, or it is the result of the enterprise's own research activities.

1.4 Determinant of accumulation of intangibles

Thum-Thysen [13] defined four basic determinants that affect the accumulation of tangibles and intangibles. The *first determinant* is government and public sector support, which we disaggregate into direct and indirect support. Direct support includes grants and incentives that are directed towards the accumulation of intangibles. Indirect support comprises determinants whose change may indirectly affect the ability of firms to invest. Here we include the tax burden. The positive impact of some policies that stimulate the accumulation of intangibles, primarily R&D, has already been demonstrated. Therefore, we expect that direct and indirect government support can stimulate investment in intangibles. The *second determinant* is the macroeconomic stability and financial conditions of enterprises. Macroeconomic instability is generally a barrier to all types of investment, including those in intangibles. As a proxy for macroeconomic stability, we use the long-term interest rate, which determines the ability of enterprises to finance their business in the long term. Financial soundness represents the ability of enterprises to invest. We use the debt to equity ratio as a proxy for financial health. We assume that macroeconomic stability and financial condition will have a positive impact on the accumulation of intangibles. The *third determinant* is quality of human capital. According to Thum-Thysen [13], most types of intangibles are human capital intensive. We use the share of tertiary-educated people in the total population and the share of employees working in R&D and technology as a proxy for the quality of human capital. We assume that an increase in the quality of human capital will have a positive impact on further accumulation of intangibles. The *fourth determinant* is the regulatory framework. There are now a number of empirical studies that look at the effects of regulation on trade, markets, business and labour. These include, for example [21,22]. We expect that the introduction of new regulations will have a negative impact on the accumulation of intangibles. We primarily observe labor regulation, via the EPL (Employment Protection Regulation) index.

2 Methodology and data

In this section, we present the chosen empirical strategy, i.e. econometric panel regression. We will present the data used and their adjustment. Based on the previous section, we define the following research questions:

1. *Which factors will have a positively influence on the intangibles accumulation?*
2. *Which factors will have a negative influence on the intangibles accumulation?*

2.1 Empirical strategy

Implementing Hausman's panel robustness test [23], we confirm the panel fixed effects regression. The use of this empirical strategy is consistent with the structure of the data and is consistent with the econometric procedure in the study e.g. Thum-Thysen [13]. Since we are working with longitudinal data, the chosen method is suitable for capturing long-term trends and relationships. This is also true given the data used, where longer time series and a small number of variables are used in the model.

We confirm that the overall panel is robust. The benchmark equation is based on the neoclassical and acceleration models of IMF [24] and the extended model of Thum-Thysen [13]. Intangibles accumulation I (1) is a function of capital stock $\Delta K^{*}_{c,t-j}$ (2), where we include a lagged effect as we account for potential slow capital adjustment and a possible endogeneity problem. We denote this lagged effect by one year as j.

$$I_{c,t} = \sum_{j=0}^{J} \omega_j \, \Delta K^{*}_{c,t-j} + \delta_j K_{c,t-1} \tag{1}$$

The model is based on the assumption that changes in capital are proportionally related to changes in economic output:

$$K^{*}_{c,t-j} = \mathrm{c}\Delta Y_{c,t} \tag{2}$$

Combining the equations and then dividing by $K_{c,t-1}$, using the fixed effect and the lagged effect by one year, the following equation (3) comes out with the mathematical prescription:

$$\frac{I_{c,t}}{K_{c,t-1}} = \gamma_c + \sum_{j=1}^{N} \beta_{1j} \frac{\Delta GVA_{c,t-j}}{K_{c,t-1}} + \varepsilon_{c,t} \tag{3}$$

where, $\frac{\Delta GVA_{c,t-j}}{K_{c,t-1}}$ represents the accelerator, expressed as a ratio of gross value added (lagged by one year) to total capital accumulation. We then extend the model to include other potential factors that may affect intangibles accumulation following the model used in Thum-Thysen [13]. Our benchmark equation is shown in the following equation (4):

$$\begin{aligned} lnY^{TOTINTG}_{c,t} &= \alpha_1 Accelerator_{c,t} + \sum_{q \in Q} \beta_1 \ln K^{\mathrm{State}}_{c,t-1} \\ &+ \sum_{q \in Q} \beta_2 \ln K^{Macro\&Finance}_{c,t-1} + \sum_{q \in Q} \beta_3 \ln K^{Human\ Capital}_{c,t-1} \\ &+ \sum_{q \in Q} \beta_4 \ln K^{Regulation}_{c,t-1} \\ &+ \alpha_2 lnSERV_{c,t-1} + \alpha_3 lnGHR_{c,t-1} + \delta_{c,t} + \varepsilon_{c,t} \end{aligned} \tag{4}$$

where, c = country, t = time. $lnY^{TOTINTG}_{c,t}$ represents the dependent variable as the share of intangibles in total capital stock. We complement this model with an indicator of servicification and participation in global value chains (GVCs). Knowledge-intensive economies have become progressively more service-oriented. Industrial production is largerly carried out within GVCs. Global value chains are becoming more serviced and the industrial sector is incorporating more and more services, which could indirectly increase the role of intangibles in the industrial sector. We implement this extension of the model to include a variable that indicates the degree of servisification of the economy. In next section more details on the variables used are presented.

2.2 *Data used*

We use the 4 categories of determinants defined by Thum-Thysen [13] as explanatory variables. These data along with the sources are shown in Table 1.

Table 1 Variables used description

Variable	*Definition*	*Source*
Accelerator	Share of gross value added and total capital accumulation.	EU-KLEMS/ EUROSTAT
State support and public and private sector		
CIT	Indirect support - Statutory corporation	OECD
GERD	Direct-Total R&D expenditure (including private) / GDP	EUROSTAT
GOV_RD	Direct - Government R&D expenditure (excluding private) /	EUROSTAT
Macroeconomic stability and financial condition		
Interest	Long-term interest rate	Ameco
D/E ratio	Debt-to-equity ratio	OECD
Human capital		
PhD	Share of tertiary-educated people in the total population 25-64	EUROSTAT
Science	Share of people working in R&D and technology in total	EUROSTAT
Regulation		
EPL	Employment protection index/ collective redundancies	OECD
Global value chains		
SERV	Share of value added in TBS in total GDP	Svetová banka
GHR	Overall participation in global value chains	OECD-TIVA

Source: own elaborations

In Table 2, we present the descriptive statistics of the variables used. The total number of observations is 352.

Table 2 Descripitve statistics

	Mean	St. error	Median	ST. deviation
TOTINTG/ Capital stock	0.383	0.014	0.254	0.279
Accelerator	0.001	0.000	0.000	0.002
GHR	3.351	0.600	0.457	11.26
CIT	0.289	0.004	0.280	0.076
GERD	1.776	0.047	1.745	0.878
GOV_RD	0.604	0.011	0.595	0.202
Interest	4.839	0.141	4.500	2.637
D/E	5.130	0.221	3.852	4.137
PHD	22.84	0.449	22.60	8.418
Sciecne	23.01	0.347	22.50	6.514
EPL	2.617	0.037	2.579	0.693
SERV	0.615	0.003	0.617	0.050

Source: own elaborations

In total, we use data from 16 EU countries. The time series is from 1995 to 2016. We used sectoral data that were fully complete up to 2016. The EU-Klems database updates the data regularly. In the econometric analysis, we identify the factors that affect the accumulation of intangible assets. The available data are sufficient to illustrate important trends, which are supported by several scientific studies. We draw data on intangibles accumulation from the INTAN-Invest [6,25] and EUKLEMS database [26]. For the standard error, we observe very low values relative to the mean, and the standard deviation is quite low, which tells us that the data are mostly close to the mean. We present the results of the regression analysis in the following section.

3 Results

We use the accelerator as the main variable, which is the ratio of gross value added to total capital accumulation. This is the indicator that links investment and output. Among the explanatory variables, we also include intangibles that are not included in the National Accounts of countries, such as Economic Competence. This makes the analysis more detailed and allow us to emphasize the first and second research question.

The first group of factors that affect the accumulation of intangibles are State support and public and private sector support. We observe a negative impact of the statutory corporate tax. Its increase has a negative effect on the accumulation of intangibles, as it reduces the available resources that have to be paid in taxes. We do not include R&D tax incentives here. These can complement direct subsidies (GOV_RD) in building innovation processes.

We further distinguish between total expenditure on science and research (GERD) and public expenditure (GOV_RD). We show that public R&D investments that can effectively strengthen the public science base stimulate the accumulation of intangibles in the economy. Total R&D expenditure (GERD), which includes private investment, has a higher coefficient (0.235) than the estimated coefficient of government expenditure (0.214). These findings are consistent with our assumptions.

The second group is macroeconomic stability and financial condition, where we include the long-term interest rate (Interest) and the debt-to-equity ratio (D/E ratio). As expected, we observe a negative estimated coefficient on these variables as rising interest rates have a negative effect on firms' investment activity. The same is true for the D/E ratio, as extremely indebted firms will not allocate investment to the acquisition of new intangibles.

The third group is the availability and quality of human capital, where we include the share of tertiary educated people and the number of skilled workers in R&D and technology. We assume a high complementarity between R&D investment and skill accumulation, as confirmed by Thum-Thysen [13]. We demonstrate the positive impact of high levels of tertiary education on increasing the accumulation of intangibles. The same is true for the R&D and technology employment variable.

The fourth group is the regulatory framework. Here we consider the regulatory behaviour of countries that may lead to difficulties in accumulating intangibles. It is true that the more regulations the less investment in intangibles, primarily R&D [21]. We use a regulatory index referred to as EPL, which focuses on legal protection of employees, collective bargaining and dismissals, and hiring on temporary contracts. Specifically, we use an index regulating collective dismissals. As expected, our results confirm the negative impact of the regulatory index. Excessive EPL may constrain the efficient reallocation of factors and may reduce productivity [27]. Our results are consistent with the findings of Thum-Thysen [13]. A rigid labor market can have negative effects on firms' efficiency and productivity.

The last group are variables that are related to participation and the form of organized production. There is a paradigm shift in the organisation of GVCs through the increasing involvement of services. It is the SERV variable, which expresses the share of the volume of value added generated in the service sector in GDP, that indicates to us how servisificated a country is. We show that participation in GVCs and a high share of servisification has a positive effect on the accumulation of intangibles.

Table 3 Results of panel data regression analysis

	TOTINTG_ln								
Fixed Effect	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
Accelerator_ln	0.355***	0.331***	0.348**	0.452***	0.370***	0.411**	0.388***	0.318**	0.316***
	(0.034)	(0.033)	(0.034)	(0.039)	(0.045)	(0.028)	(0.033)	(0.035)	(0.029)
CIT_ln $_{t-1}$	-								
	(0.038)								
GERD_ln $_{t-1}$		0.235***							
		(0.037)							
GOV_RD_ln $_{t-1}$			0.214**						
			(0.044)						
INTEREST_ln $_{t-1}$				-0.075***					
				(0.015)					
D/E_ln $_{t-1}$					-0.070***				
					(0.019)				
PHD_ln $_{t-1}$						0.474**			
						(0.035)			
SCIENCE_ln $_{t-1}$							0.469***		
							(0.068)		
EPL_ln $_{t-1}$								-	
								(0.093)	
SERV_ln $_{t-1}$									2.108***
									(0.174)
GHR_ln $_{t-1}$	0.800***	0.716***	0.846**	0.895***	1.008***	0.257**	0.572***	0.872**	0.559***
	(0.073)	(0.071)	(0.065)	(0.061)	(0.059)	(0.073)	(0.083)	(0.062)	(0.061)
Balanced	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. of Obs.	336	336	336	336	336	336	336	336	336
R2	0.521	0.550	0.526	0.526	0.491	0.675	0.557	0.530	0.652
F_stat.	***	***	***	***	***	***	***	***	***
Hausman	0.000	0.000	0.000	0.000	0.000	0.000	0.0067	0.000	0.000

Source: own elaborations; * *, **, *** indicates statistical significance at the level 10%, 5% and 1% levels.

4 Conclusions

Throughout history, industrial revolutions have caused dizzying changes in economies, businesses and people's lives. The Industrial Revolution, known as Industry 4.0, is having the greatest impact [28,29]. The accumulation of intangible assets has great potential to influence the way Industry 4.0 is implemented.

We have confirmed in a sample of 16 EU countries that public direct and indirect support, together with available and quality human capital, has the potential to positively stimulate the accumulation of intangibles. Conversely, barriers that negatively affect the growth of intangibles include macroeconomic and financial corporate instability and the regulatory framework.

We indetify the factors unlocking the accumulation of intangibles. This is primarily in the area of government direct and indirect support for investment in innovation assets - R&D and other innovation assets. It is about creating the space to encourage private investment in innovation assets, intangible ICT assets and economic competences. It is associated with the macroeconomic stability of the country, which creates all the preconditions for direct and indirect state support.

A significant driver positively influencing the accumulation of intangibles is the development of human capital quality. We have demonstrated that highly skilled human capital has a substantial impact on the accumulation of intangibles. This relationship may hold *vice versa*, where investments in intangibles have the potential to stimulate workforce development.

An important element is also the servicification of GVC, which means that the service sector also contributes to industrial production, encompassing activities characterized by a high degree of value-added. This is a significant factor in developed economies that stimulates the accumulation of intangibles, even in industrial production.

A proper understanding of the factors that influence the accumulation of intangibles can help policy makers to adopt legislative frameworks. Set the regulatory framework, create conditions for stable corporate financial health, improve the business environment and ensure a sustainable macroeconomic balance. Implementing the right policies can thus stimulate investment in intangibles, creating a knowledge-based economy that can result in improved adaptation of Industry 4.0.

The limitation of the research is to identify in more detail the factors influencing the accumulation of intangible assets. Future research could be directed towards a separate investigation of the impact of factors on specific types of intangible assets, such as ICT intangible assets, innovation assets and economic competencies.

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