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Basic hydrogel polymer materials for 3D printing

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Abstract: Currently, 3D printing of hydrogel scaffolds, which are used in tissue engineering to come to the fore, is gaining prominence in order to restore the structure and function of soft tissues and organs. For successful printing of soft constructs, the FRESH method using a support bath is used, thanks to which the printed hydrogel is kept in the desired shape during solidification. The aim of the study is to create an overview of hydrogel materials and their properties affecting printing, to summarize previous printing of hydrogel scaffolds. The choice of material, the method of crosslinking for the formation of the hydrogel, is taken into account, while at the same time the non-toxicity and compatibility of the material with the biological environment. Specific emphasis is placed on adapting the technological procedure of the FRESH method, where the chemical composition of the support bath must be in accordance with the crosslinking agent and the rheological properties of the printed hydrogel.

1 Introduction

Polymers are large molecules (macromolecules) made up of long chains or cycles formed by regularly repeating parts, called building blocks or monomer units. Their number indicates the degree of polymerization n, which has a value of 10 to 106 [1].

Monomers are simple molecules that undergo a polymerization process to form polymers. Therefore, monomers are also called polymer building blocks [1].

Polymerization is the process by which two or more molecules react and combine to form polymers - long chains of monomer repeat units.

Polymers can be divided into two categories according to the source and origin of the polymer:

1. Natural polymers.
2. Synthetic polymers [2].

Natural polymers - also called biopolymers - perform key functions in organisms such as building and structural proteins and polysaccharides, nucleic acids, energy supply and storage. Natural polymers include silk, rubber, cellulose, wool, keratin, collagen, starch, DNA and nucleic acids [3].

Synthetic polymers are prepared by a chemical reaction, often in a laboratory. A wide range of physical and chemical properties can be achieved on the basis of monomeric units, polymerization reactions and copolymer formation from different components in adjustable concentrations. PVC (polyvinyl chloride), polystyrene, synthetic rubber, silicone and others are basic examples of synthetic polymers [4].

A common feature of synthetic polymers is their stability, which is often required in everyday life and the medical field. The disadvantage of this stability is that these polymers cannot decompose naturally, leading to accumulation in the environment. This can cause various toxic effects in the environment. One way to decompose or destroy these synthetic polymers is to burn them or heat them to very high temperatures, which is also not an environmental approach due to the release of toxic gases [5,6].

According to the arrangement of the polymer molecules in space, they are classified as linear polymers, branched chain polymers and spatially crosslinked polymers (Figure 1).

1. Linear polymers: The basic building blocks have monomers arranged in one row, they are produced using

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straight and long chains of monomers joined by a single bond. For example, polyester, nylon, Teflon, etc.

2. Branched chain polymers: They are formed by the interconnection of some parts of linear chains by chemical cross-links. They represent polymers that branch in a plane. For example, polyethylene, glycogen, starch, etc.

3. Spatially crosslinked polymers: These polymers are formed when building blocks bond to a three-dimensional network through strong covalent bonds. For example fiberglass, adhesives, polyester, etc. [7].

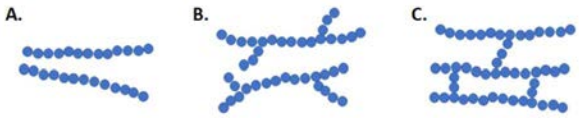

Figure 1 Scheme of polymer structures: A. linear, B. branched, C. spatially crosslinked [7]

Polymeric substances can be formed in various ways (see Figure 2) and are based on the formation:

1. Polymers formed by polymerization: Polymerization can be defined as a multiple addition reaction in which no by-products are formed. The molecules of the substance entering the reaction are gradually (multiple) combined into larger units, the resulting product being a monomer with multiple bonds.

2. Polymers formed by polycondensation: Polycondensation is a multiple reaction in which at least 2 different monomers react and the result is the removal of small molecules such as water, ammonia and the like. Reactions are always reversible and have a stepwise course, so the addition of a substance creates a new step with a new product and reaction and can be stopped at any time by the absence of a reactant. The reactions use catalysts which affect the course of the reaction. The products are generally called polycondensates.

3. Polymers formed by polyaddition: Polyaddition is the transition between polymerization and polycondensation. The reactions tend to be chain-linked, re-unsaturated monomers, and no by-product is formed [7].

Polymers are used for various purposes depending on their flexibility, tensile strength and the like. The mechanical strengths of polymers are determined by hydrogen, ionic or covalent bonds.

Based on intermolecular forces, polymers can be divided into the following categories:

1. Elastomers: Elastomers are solids with elastic properties. These polymers have weak molecular bonds between the monomers, which helps the monomers to stretch easily. For example, polybutadiene, polyisoprene, etc.

2. Fibers: They are made of chains of similar structures, which facilitates their interconnection and have high tensile strength. For example, terylene [7].

3. Thermosets are made of a liquid or soft solid which, when cured by heat or radiation, forms an insoluble, irreversible polymer, i.e., the thermosets form irreversible chemical bonds. Thermosets tend to be rigid and have a high molecular weight. Examples of thermosets are epoxy resin, polyester, acrylic resin, polyurethane, rubbers and vinyl esters.

4. Thermoplastics are solid in the cold but are flexible and malleable when heated above a certain temperature. While thermosets form irreversible chemical bonds, thermoplastic bonds are weakened by rising temperatures. While thermosets decompose and do not melt, thermoplastics melt into a liquid state by heating. Examples of thermoplastics include nylon, Teflon, polypropylene, polycarbonate and polyethylene [4].

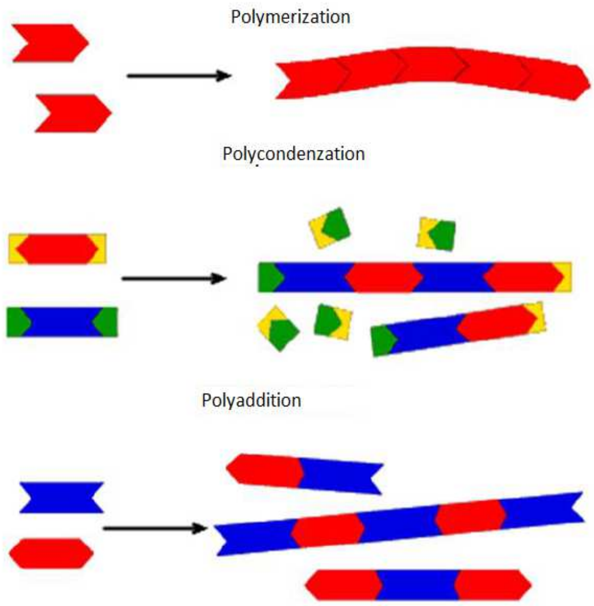

Figure 2 Types of polymer synthesis

1.1 *Biodegradable polymers*

A special group of polymeric substances is defined by a property specifically monitored for environmental reasons, and at the same time it is an important condition in the field of biomedical development of materials. Due to their strong bonds, a large number of polymers are very difficult to break and thus degrade. This causes the accumulation of non-degradable polymers in the environment, causes an imbalance in nature and can become toxic to the environment, living organisms as well as humans. In order to prevent the toxic effects of polymeric materials on the biological environment, emphasis is placed on testing and verification of the so-called biological tolerance and biodegradability. Such materials behave harmlessly in the biological environment and may be capable of degradation, while their degradation intermediates do not cause toxic reactions to living organisms [6].

1.2 Hydrogels as polymeric materials

The excellent mechanical and water of the acknowledging properties are a characteristic feature of hydrogel, which are based on synthetic polymers, but also have major disadvantages, namely poor biological degradation and potential toxicity, which significantly narrows the profile of their biomedical applications (see Table 1) [8].

Table 1 Summary of properties of natural and synthetic polymers

	Advantages	**Disadvantages**
Natural polymers	In natural organisms	Limited sources
	Easily degradable	Low mechanical properties
Synthetic polymers	Reproducibility	Emphasis on biocompatibility
	Artificially created	Lower degradability
	Good mechanical properties	Products of degradation could be toxic
	Customization of properties	Could need toxic polymerization solutions

Compared to synthetic polymers, hydrogels based on natural polymers have great potential for application in biomedical areas due to their biocompatibility and biodegradability. A natural polymer is a high molecular weight compound that has a linear long chain formed by repeating units as a basic structure, commonly found in animals, plants and organisms such as collagen, chitin, alginate, cellulose, starch, agar and the like [3].

In practical applications, hydrogels must carry their own weight without breaking, and in addition they must withstand a certain external force from the environment in which they are placed. The hydrogel based on natural polymer generally has poor mechanical properties, which considerably limits its application possibilities. Therefore, it is very important to improve the mechanical properties of hydrogels based on natural polymers, while paying attention to the conditions of its subsequent application, which must remain non-toxic and biocompatible [8].

2 Properties of hydrogels

2.1 Biological properties

2.1.1 Cytocompatibility

For tissue engineering, cytocompatibility is a crucial issue in selecting a applicable biomaterial. ECM-derived hydrogels naturally have cytocompatibility assets. More all-important, the numerous binding sites in hydrogel materials can allow for synergy between cells and the hydrogel matrix. Polysaccharides and synthetic hydrogels may also be compatible with cells but lack bioactive sites for cell connection and attachment. Further modification is needed to simulate the physiological microenvironment of the tissues [9].

2.1.2 Biodegradability

The ability of implants to be gradually broken down and washed out of the body by means of their biodegradability is essential in some clinical transplants. In addition, many experiments have shown that biodegradability is also crucial at the cellular level. In one study, a cell-degradable hydrogel was shown to encourage the deposition of encapsulated chondrocytes in the extracellular matrix. In another study, cells cultured in hydrogels with a more rapid rate of degradation exhibited increased migration and proliferation. Such a process is shown in Figure 3. Biodegradability offers that the mild degradation process and the degradation and degradation products of biomaterials have small effect on cell survival [10,11].

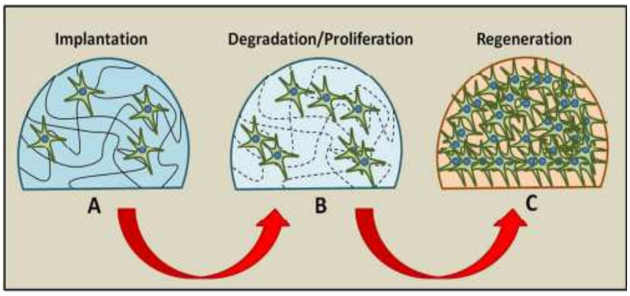

Figure 3 The ideal pathway to hydrogel mediated tissue regeneration [12]

2.1.3 Transport environment

For enduring tissue functions, mass transport of biological and chemical molecules between cells and tissues is indispacable. Hydrogels are matrices with interconnecting pores and large amounts of water. This property allow the wide distribution of small soluble molecules. In hydrogel-based tissues, biochemical factors such as gas, nutrients, proteins, metabolic wastes, etc. can be well transported across vascular boundary and through conditioned tissues [9].

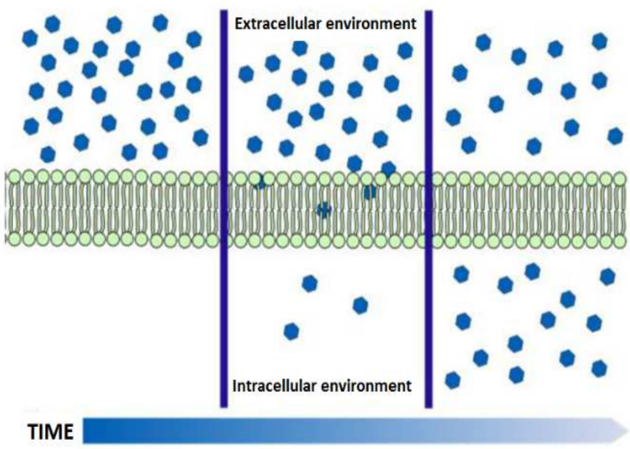

Figure 4 The ideal pathway to hydrogel mediated tissue regeneration [12]

The chemical gradient (*see Figure 4*) created during in vivo bulk transport is important as it affects cell migration, which is associated with diverse physiological and pathological mechanisms such as inflammation, embryonic morphogenesis, cancer metastases, etc. Chemicals that diffuse within the hydrogel also create a diffusion gradient in the hydrogel, and this can be used to search physiological and pathological phenomena in vitro, which so far suggest a higher importance of the chemical gradient at the tissue level than at the level of neighbouring cells in contact [12].

2.1.4 Rheological properties of hydrogels

The Department of Rheology studies the deformation and flow of materials depending on the applied force. In the extrusion-based process, the ink is initially in the storage vessel at rest (no flow). When forces are applied, it undergoes deformation and flows under high shear conditions as it moves through the nozzle walls. It then takes on a new shape until it finally returns to a new state of rest [14,15].

Viscosity, viscoelastic modulus in shear, material recovery behaviour, and shear stress are crucial rheological characteristics associated with these transitions. It may be associated with ink performance before (rest and flow initiation), during (flow behaviour - extrudability). and after printing (printing accuracy, form fidelity and adhesion), see Figure 5.

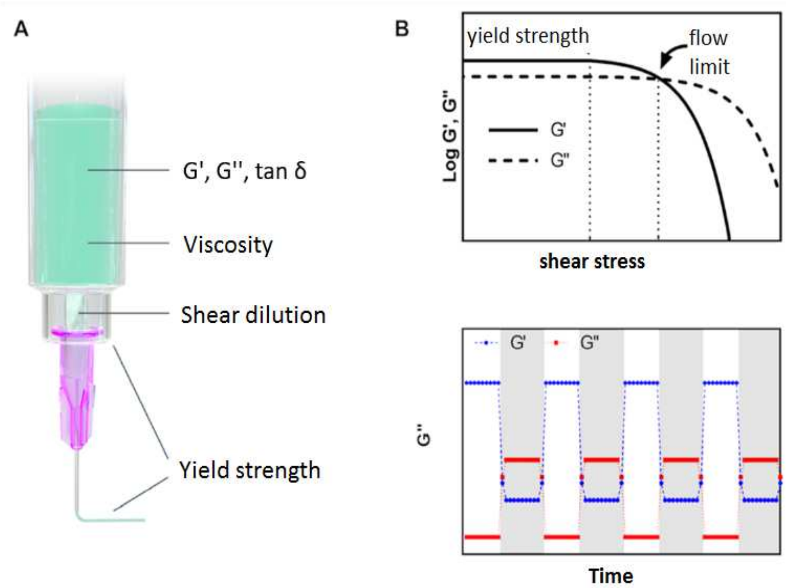

Figure 5 Rheological properties during the printing process (G 'and G' 'denote sol-gel phases and Tan δ represents the damping factor) [14]

3 3D printing of hydrogels

Overview of 3DP methods for hydrogel materials

In general, printing materials must meet the requirements of:

1. have an adequate viscosity to allow printing and structural stability,
2. be able to create a 3D structure in a few minutes,
3. have satisfactory mechanical properties,
4. be biocompatible,
5. have adequate degradation kinetics,
6. create non-toxic by-products of degradation,
7. be biomimetic,
8. be able to control the release of molecules or drugs [16].

Moreover, bio-inks should be easy to produce and process, be affordable and commercially available [16].

Scaffolds are structures that are specifically designed to mimic the extracellular matrix (ECM) of living tissue, simulate the in vivo environment, and allow for desirable cellular interactions that contribute to the formation of new functional [11,17,18]. The constructed scaffolds are used as a supportive environment in which the cells are "deployed" and the scaffolds thus support the formation of three-dimensional tissue. Scaffolds usually serve at least one of the following purposes:

- allow cells to attach and migrate,
- supply and retain cells and biochemical factors,
- allow the diffusion of vital cellular nutrients and expressed products,
- exert certain mechanical and biological effects on modifying the behaviour of the cell phase [17,19,20].

The scaffold design for biomedical applications should meet the needs of some of the basic requirements schematically illustrated in Figure 6:

1. high porosity (preferably 100% interconnection for optimal nutrient flow and tissue overgrowth by cells);
2. relevant geometry and pore dimensions (5-10 times the cell diameter);
3. biodegradable with adjusted (or modifiable) degradation time;
4. maintaining mechanical integrity for a specified period of time;
5. should have appropriate cell-biomaterial interactions; and
6. should be easy to manufacture and reproducible [11,17,20].

Bioinks or bioarmaments are materials used for the production of constructed / artificial living tissues using 3D printing. These inks usually consist of biomaterials that contain or encapsulate cells or are capable of adhering cells to the surface of the biomaterial. The combination of cells and biopolymer hydrogels is defined as bionic [14,21].

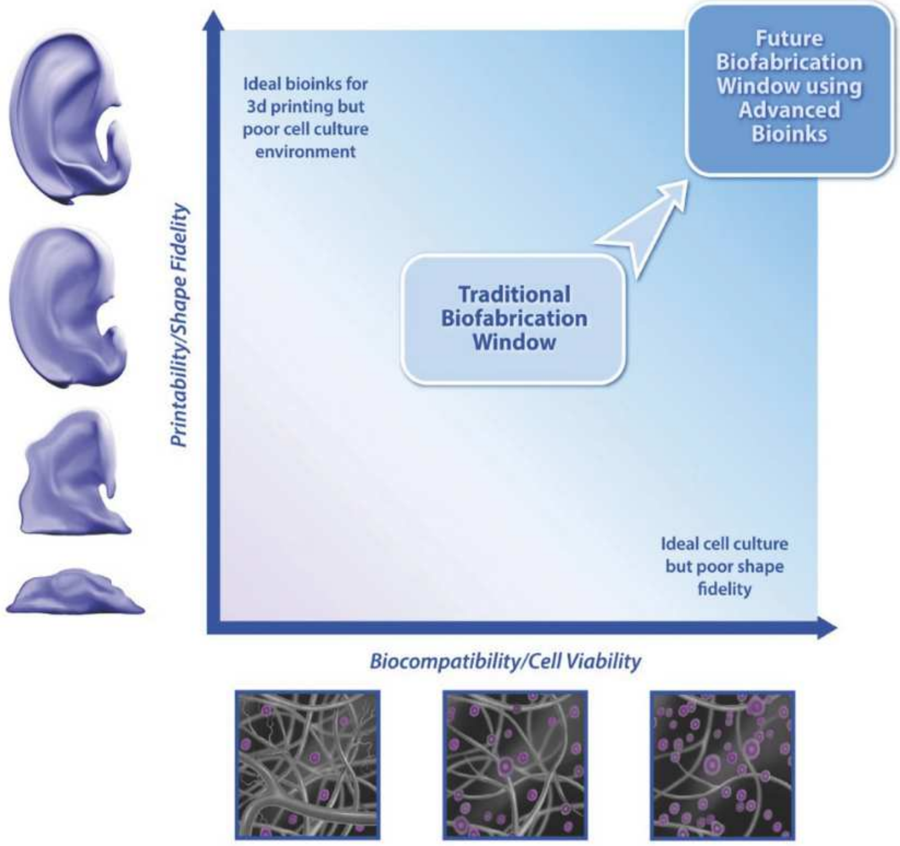

Figure 6 The biofabrication window [21]

3.1 3D printing methods of hydrogels without supporting structure

A very relevant characteristic of each technique will be its resolution. Each technique has its limit of the smallest details that can be produced. This limit represents the extent to which the planned object is feasible while maintaining the required level of detail [23].

As not all rapid prototyping (RP) techniques are applicable to the processing of hydrogel materials, this requirement has redistributed a number of RP technologies. In addition, the production of hydrogel scaffolds requires mild processing conditions, which again eliminates some technologies unsuitable for hydrogels. This chapter provides an overview of the most important techniques developed for 3D printing of hydrogel materials, including their advantages, disadvantages and limitations, which have emerged in previous studies [24].

3.2 Methods of 3D printing of hydrogels with supporting structure

As 3D printing runs layer by layer, many 3D printing materials undergo solidification of the soft material to hard, allowing previous structures to support the weight of the next layer as well as their own weight. However, hydrogels often remain deformable even after crosslinking [25,26].

Insufficient support for previously printed layers can cause the material of the previous layers to fold when the layer is added under the influence of its own weight. This affects the print quality of the final structure and is one of the most common causes of three-dimensional scaffold design failure [23]

Although it is common that even relatively rigid gels can show considerable softening during printing, this phenomenon is particularly pronounced for very soft constructions, which are of interest for applications mimicking the mechanical properties of many biological soft tissues [23,27].

Biological hydrogels are difficult for 3D printing because they must be supported during the gelling process so that they do not collapse and deform due to their own weight. The need for support materials is common in many AM techniques, yet it is particularly difficult to prevent damage to materials and potentially integrated cells for such soft materials where the modulus of elasticity is less than 100 kPa (see Figure 7). In addition, for hydrogels, there is a narrow range of mechanical, thermal and chemical conditions that must be met to maintain the shape of the hydrogel skeletons [20,25].

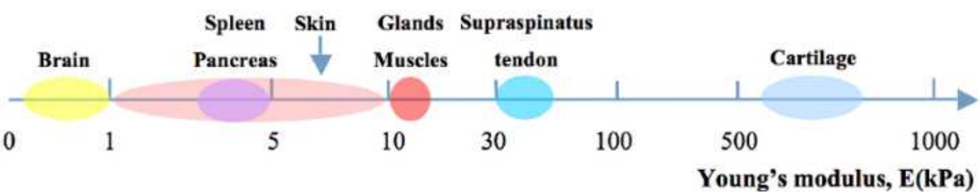

Figure 7 Young's modulus of elasticity for natural soft tissues and organs [20]

3.3 Key factors affecting the press

The most important characteristic for 3 D printing is printability. This ability to create and maintain reproducible 3D ink scaffolds using 3D printing techniques affects the structure of printed spacesuits and consequently acts on their mechanical and biological properties [28].

Structures for use as support structures for living cells can be made using extrusion-based printing techniques. For this purpose, hydrogels for their environment favourable to cells and high water content are widely used. Hydrogels can be crosslinked physically or chemically, which affects the quality of the extruded 3D structure. Crosslinking hydrogels is a time consuming process and the hydrogel as such may be dimensionally stable as a solid or flow as a liquid, thereby deviating substantially from the desired design. Due to the poor compressibility of hydrogels, printed scaffolds can sometimes collapse and do not form a 3D structure [28].

The concept of printing is important because the difference between a printed scaffold and the ideal design required can affect mechanical and biological properties, including mechanical stiffness and cellular functions [28].

Naghieh et al. divided the factors influencing printing into three categories: scaffold design, ink, and the printing process. Scaffold design parameters that may affect printability include pore size, filament orientation, and layer thickness. The critical factor associated with an ink is its flow behaviour and physical properties. Relevant parameters of the printing process include the mechanism of crosslinking (polymerisation) and the parameters of the printing itself, such as pressure and speed [28].

3.3.1 Scaffold design

Factors associated with scaffold design that affect printing include fiber orientation, fiber spacing, pore size, and layer thickness. However, a limited number of studies have identified key elements that play an important role in printability in terms of scaffold design [28].

Some studies have looked at the effect of fiber orientation during printing on the surface and overall porosity of the scaffold, cf. Figure 8. For example, changing the orientation of each fiber near the edge by 45 ° instead of 90 ° can reduce the amount of ink required. Structures with larger inner pores require less ink, on the other hand they endanger the stability of the structure [28] [29].

The thickness of the layer can affect the pore size, and by changing the layer thickness during printing, more accurate pore sizes can be achieved. The main reason for the change in layer thickness during the printing process is that the pore size does not remain constant from top to bottom of the scaffold, even though a constant layer thickness is used during the printing process. This change in pore size is due to the weight of the following layers. [30]. Scaffolds with more precise geometries were made using smaller layer thicknesses. A recent study showed that increasing the layer thickness by 30 μm not only improved production speed, but had no effect on the performance, dimensions and geometry of the spacesuits [31,32].

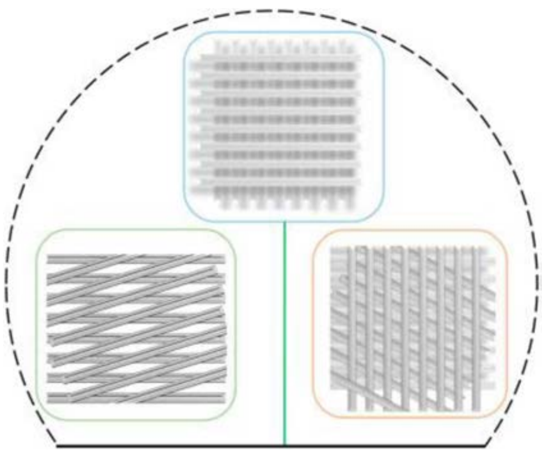

Figure 8 Schematic representation of scaffolds with different fiber orientations (90 °, 45 °, 60 °) [32]

A complex view of the structure created by additive manufacturing is their specific shape. There are studies that have looked at the effect of the shape of a spacesuit on its subsequent use. For example, the work of Zhang et al. focused on the printing of the so-called "Honeycomb patern" (see Figure 9). The shape of beeswax was chosen in the press to create spheroids, which made it easier to attach mesenchymal cells to human bone and enhance cell differentiation [33].

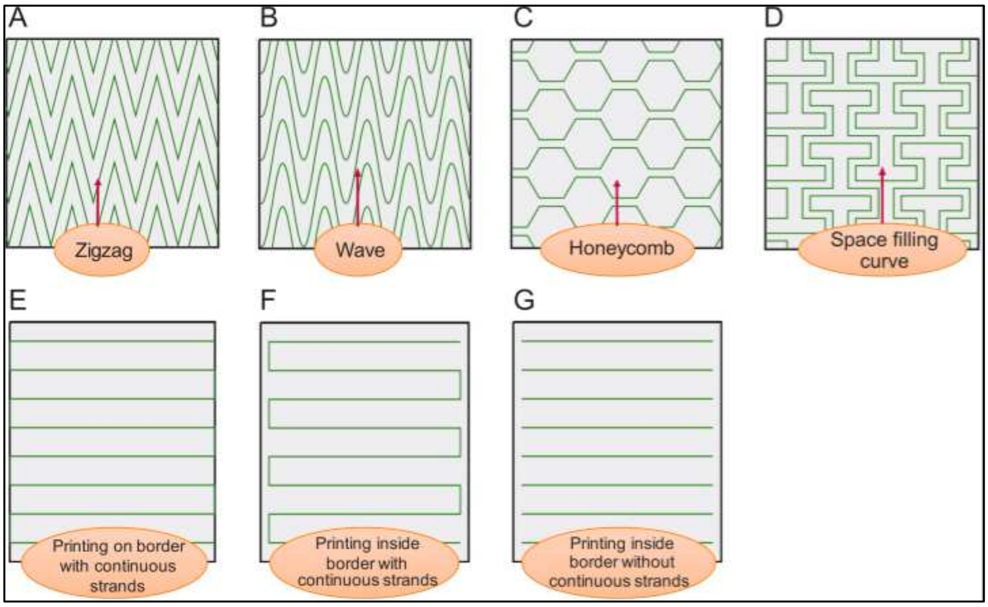

Figure 9 Different patterns for scaffold printing [32]

Several patterns are used to create hydrogel scaffolds, the choice of which depends on the required function of the scaffold. The zigzag pattern of hydrogel material, which due to its curvature requires support in 3D printing, was implemented to create a fabric structure. Square wave patterns are used to form a scaffold due to their ability to increase the diffusion of nutrients and drugs into the core of the fibers pressed layer by layer. Another type of pattern that is used for continuous extrusion to improve the printability of complex structures is space filling. This pattern has also been used to facilitate cell adhesion and grow faster [34,35].

3.3.2 Ink

Hydrogels from both natural and synthetic polymers are commonly used bioapplication materials because they can provide a highly hydrated environment suitable for cell adhesion along with mechanical integrity. Polycaprolactone (PCL), polylactic acid (PLA) and poly (lactic-co-glycolic acid) (PLGA) are synthetic polymers often used in 3D printing that exhibit high printing and mechanical stiffness. The lack of sites for cell adhesion, the high printing temperature, and the organic solvent needed to produce ink with these materials limit the production of cell contact structures, and thus for tissue engineering and drug applications [30,36,37].

Natural materials such as alginate, collagen, gelatine and chitosan are more gentle and less toxic to cells; however, they usually lack sufficient mechanical rigidity and longevity [38].

3.3.2.1 Hybrid inks

A preferred strategy for producing printing inks is to mix different types of materials with alginate. The aim is to create hybrid or composite scaffolds that show improved printing, mechanical properties and biological characteristics of alginate scaffolds. Pure alginate does not have the adhesion sites needed for cell attachment, and therefore scaffolds made from alginate and gelatine may be a solution for improving the biological properties of alginate scaffolds [39,40].

Gelatine is widely used to improve the mechanical properties and printability of hydrogel scaffolds. Mr. et al. analyzed the properties of the scaffolds containing gelatine together with alginate and found a high water retention rate. These studies suggest that the combination of different ink-producing materials can aid in printing and allow better control of the properties of the scaffolds to achieve the required scaffold functions [41].

3.3.2.2 Ink surface tension

Since the attraction of liquid molecules is stronger than the attraction of molecules in air, a liquid-air surface tension arises at this interface. The contact angle between these media indicates compressibility, which is referred to as interfacial energy.

A surface tension arises at the liquid-air interface because the attraction of the liquid molecules is more pronounced than the attraction of the molecules in the air. Surface tension is a liquid-air interfacial energy and can affect compressibility due to the contact angle between the two media. This angle indicates the degree of hydrophilicity of the scaffold, that is, the hydrophilicity of the scaffold can potentially support cell growth more because higher wettability improves biological behaviour [28].

In general, if the print substrate has a high surface tension compared to the surface tension of the ink, the ink will melt. Conversely, a low-energy hydrophobic substrate results in less spillage and a higher contact angle [28].

Most inks used in extrusion-based bioprinting have shear thinning effects, i.e., fibers applied at high flow rates have lower viscosities. Such fibers generally have smooth surfaces at the exit of the nozzle, leading to greater surface tension (see Figure 10). It follows that the high ink extrusion rate affects the lower viscosity of the extruded fibers [28].

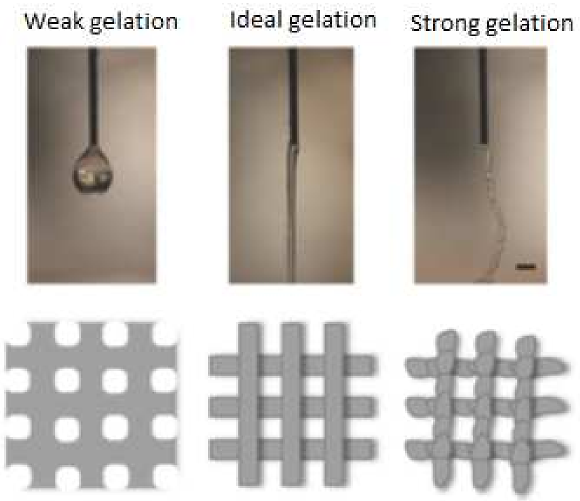

Figure 10 Influence of the degree of gelation on the quality of the final product

By affecting the surface tension of the ink and the substrate, printability can be improved or excessive ink expansion can be reduced. There are three approaches that can be used to manipulate material properties:

1. In order to avoid spillage of inks with a lower surface tension and at the same time to obtain a low energy surface such a printing substrate could be treated with a hydrophobic material. Substrate coating has been introduced as a suitable technique for modulating the surface energy of a substrate without directly affecting the ink material.

2. High viscosity ink can be used to achieve minimal ink spreading and spilling on the substrate. However, not all high viscosity inks are suggested due to the need for high extrusion pressure, as nozzle clogging may occur. Another consequence of the use of highly viscous material is unfavourable conditions for adhesion and subsequent cell viability.

3. Another approach to solving the problem of low print quality is to increase the speed of the process of crosslinking the hydrogel material or solidifying the extruded scaffold. This can be achieved by modifying the crosslinking mechanism (see Chapter 2.1) or the porosity of the scaffold - the higher the porosity, the faster the crosslinking rate [28].

3.3.3 The printing process

Printing parameters and the conditions under which printing takes place are especially important when printing complex 3D structures with different levels of porosity. Factors to consider in a printability study are the type of needle used for printing, the pressure developed, and the extrusion rate. Due to the interaction between the ink and the needle, the surface energy of the needle should also be considered [41].

For hydrogels, cross-linking during printing is a specific criterion, as pre-printing cross-linking increases the possibility of nozzle clogging, while cross-linking after 3D printing increases the likelihood that instability or disintegration of large structures will occur in large multilayer structures [28].

Thanks to their hydrophilic properties, biocompatibility and flexibility, hydrogels are used in several biomedical applications, such as drug carriers, absorbable sutures and injectable biomaterials. Protein-based polymers simplify some cellular functions, but the disadvantage is a relatively slow cross-linking rate compared to polysaccharides such as chitosan, which have polymerization rates more suitable for their printing [28].

Physical hydrogels are formed by a variety of reversible bonds, including hydrogen bonds, hydrophobic interactions, electrostatic / ionic interactions, as well as combinations thereof. The sol-gel transition in physical gels is usually triggered by stimuli such as pH, temperature, magnetic field or the addition of suitable ions. Physical chitosan hydrogels do not need polymerization aids during crosslinking, which makes them suitable for the cells due to their low toxicity. However, these hydrogels often have low mechanical stiffness and it is also difficult to reproduce their properties, such as pore size or dissolution rate [28].

I. Laser-based systems based on the photopolymerization process.

II. Systems based on extrusion of (pre) polymers by means of a nozzle.

III. Printer and binder injection based systems [25].

4 Results and discussion

While AM technologies used in the processing of metals, ceramics and thermoplastic polymers have inspired the field of biofabrication, these "classic" AM approaches generally involve the use of organic solvents, high temperatures or crosslinking agents that are not compatible with living cells or biomolecules. Hydrogels must be processed under more favourable cell conditions, which was taken into account during the development of the methodological manual for the production of hydrogel scaffolds by AM technologies.

Another criterion is to solve the problem with support structures during printing. Although the need for support materials is common in many AM techniques, for soft hydrogels with a modulus of elasticity <100 kPa, this problem has been solved by using the FRESH method, which uses a support bath. The liquid hydrogel is then pushed into it and the support bath thus holds the hydrogel in the desired place thanks to buoyancy until it solidifies.

5 Conclusion

Increasing demands on medicine itself force rapid progress in the field of materials applicable in this area. the conditions for approval of materials are very high. Today, only the biocompatibility of the material is not enough, but the material must meet a number of requirements and physical advantages. In the field of 3D printing, the use of hydrogel materials, which have high potential in the field of tissue engineering and regenerative medicine, is important. The printing process itself is a complicated event and several requirements must be met.

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Mathematical modelling of process planning problem

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Abstract: This paper discusses a mathematical modelling of process planning problem. As everybody knows, a component has a set of operations derived from its design. Each operation can be performed by a set of machines, which are associated with it. Each such machine has a setup cost and processing cost per unit period. The goal is to choose the machine for each operation in such a way that the total cost, which is the sum of the setup costs and processing costs of the machines associated with the operations of the component, is minimised by taking the desired production volume of that component per period into account. The topic of processing planning is explored in this study as a linear programming model.

1 Introduction

Companies are engaged with manufacture of products to satisfy the needs of households and also industries buying industry goods. Each product consists of a set of components. These are to be manufactured such that the total cost of manufacture of the components and in turn the product is minimized to have competitive advantage in the market.

Immediately after the design of a component of a product, the process planning function aims to select the cost-effective machine for each operation of that component in an effort to lower the component's overall manufacturing cost.

2 Literature review

This section reviews the literature in the field of process planning.

Hayes and Wright (1989) suggested directing search using future interactions to automate process planning. Automatic process plans for making metal parts on a CNC machine tool are created by an expert system known as Machinist. It is a part of an overall strategy to automate the workshop. It works with prismatic items that have one or more sides with carvings on them. When one group of traits is removed first, parts of this kind might interact. These linkages need to be appropriately considered while planning and organising the machining operations. The machinist programme, which has been created to be an essential part of CAD systems, facilitates the creation of manufacturing plans.

Mcginnis et al. (1992) a framework for planning the printed circuit card assembly process was created, and it was used to assess the state of the research on appropriate models and solutions. In the beginning, they provided a general review of the language, assembly methods, and assembly system functions that are essential to printed circuit boards. They then assessed the existing literature, proposed a decision hierarchy, and identified areas that still needed investigation.

Kiritsis addressed strategies and problems related to knowledge-based expert systems for process planning (1995). With some help from the author's survey research, it is mostly based on literature. The primary difficulties are categorised after a brief explanation of process planning, and the appropriate approaches and strategies for resolving them are given.

Sormaz and Khoshnevis (1997) A quick analysis of the knowledge representation techniques used in reported existing CAPP systems is followed by a full explanation of the process planning function and the knowledge it requires. Then, an object-oriented approach to knowledge representation is described. This approach makes it straightforward to interact with other CIM modules for computer integrated manufacturing and allows CAPP to be incorporated both upstream and downstream. In addition to their relationships to features, tools, and machines, the entities engaged in the machining process are explained. The network depiction of the process plan, which accommodates alternative plans, is explained. An example is used to demonstrate how the implementation of the scheme is done in a functional process planning system prototype. The suggested representation's benefits are listed.

Layered manufacturing is a new production technique with the potential to increase output scope (LM). A key element of LM is process planning. By Kulkarni et al., the literature in this emerging topic is described, conceptualised, and reviewed (2000). As the report draws to a close, predictions about probable future areas for research in this area are given.

The description of a disassembly plan includes a disassembly bill of materials (DBOM), the order of processing steps, the type of disassembly action, the component or fastener worked on each step, the tools used, and the outputs of material and pieces. The two aspects of the planning issue for the disassembly process are the development of a feasible plan and its implementation at a facility (DP3). The DP3 model was introduced and explained by Sanchoy (2002).

This model describes the construction of the disassembly process plan, documentation, and evaluation processes. One of the main advantages of this model is its framework for communicating product information from the original product manufacturer to the user and the end-of-life disassemble through the disassembly bill of materials (DBOM). Because it specifies a plan that a manufacturer can swiftly develop and successfully disseminate to the disassembly community, the DP3 is a descriptive model. The user can decide the sequence of the disassembly procedures, nevertheless. The model introduces a variety of standards for identifying unfastening operations, damaging acts, and the required equipment. The DP3 model also provides an economic evaluation of different ideas.

For instance, methods that combine additive and subtractive manufacturing processes have received a lot of interest recently. This is due to the fact that they can profit from the overall advantages of combining various processes. There are, however, few process planning approaches that can effectively mix additive and subtractive manufacturing processes. to enable the fusion of the inspection process with the advantages of additive and subtractive technologies.

Newman et al. (2014) the interactive framework was introduced. Through a range of case studies, Re-Plan, a system for process planning based on interactivity, illustrates the potential of combined process manufacturing.

CAPP, or computer-aided process planning, is a tool that process planners can utilise to assist them in their planning activities. For combining computer-aided design (CAD) and computer-aided manufacturing, it is regarded as a crucial piece of technology (CAM). Due to the globalisation of the market and industry, CAPP research currently faces new challenges.

Yusof and Latif (2014) aimed to present a comprehensive review of CAPP based on features, knowledge, genetic algorithms, artificial neural networks, fuzzy set theory, fuzzy logic, Petri nets, agents, the Internet, STEP-compliant methods, and functional blocks (FB) methodologies/technologies throughout the past 12 years (2002–2013). The objective of this study is to provide a current survey with a graphical representation of the past, present, and future of CAPP for easy understanding. This paper's format consists of an introduction, a survey of CAPP, a discussion, and a conclusion. It also includes an overview of CAPP and its methodology, procedures, and technologies.

Research Gap: According to the literature, the majority of researchers concentrated on the process planning domain using the component's shape and size. However, by considering its amount of production each period, the most cost-effective machine is not chosen for each operation of the component. In order to choose the most cost-effective machine for each operation of the component and reduce the overall cost for the specified volume of production, a linear programming model has been developed in this study.

3 Objective

The goal of this research is to create a linear programming model to choose an affordable machine for each operation of the component in order to reduce the component's overall cost for a certain volume of production each period.

4 Linear programming model

A component with m operations is an example. On a group of machines [j = 1, 2, 3,..., n _ i], where i = 1, 2, 3,...,m, any operation i can be processed.

Let, *m* be the component's total number of operations.

If i = 1, 2, 3,... m, then n_i is the total number of machines that can process the operation.

The setup cost per unit of the operation I on its approved machine is sc ij. j = 1, 2, 3,...,m and i = 1, 2, 3,......, n_ i

The processing cost per unit of the operation I on its qualified machine is denoted by the symbol pcu _ij. j= 1, 2, 3,......, n _i and i = 1, 2, 3,....

v is the component's monthly production volume, for example.

If an operation employs a machine, then y _ ij = 1, where I = 1, 2, 3,..., m and j = 1, 2, 3,.., and n _ i.

= 0, i = 1, 2, 3,..., m and j = 1, 2, 3,..., n_ i if the operation i does not employ the machine j.

Table 1 provides examples of setup times, processing times per unit for each qualified machine in each operation of the component, and production volumes for that component over a period of time, such as a month.

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Table 1 Generalized data for process planning

		1	2	3	.	i	.	m
	Operation Number i	1	2	3	.	i	.	m
	Number of qualified machines (nm_i)	n_1=4	n_2=2	n_3=3	.	n_i =3	.	n_m =4
Machine j	1	sc_{11}	sc_{21}	sc_{31}	.	sc_{i1}	.	sc_{41}
		pcu_{11}	pcu_{21}	pcu_{31}	.	pcu_{i1}	.	pcu_{41}
	2	sc_{12}	sc_{22}	sc_{32}	.	sc_{i2}	.	sc_{42}
		pcu_{12}	pcu_{22}	pcu_{32}	.	pcu_{i2}	.	pcu_{42}
	3	sc_{13}		sc_{33}	.	sc_{i3}	.	sc_{43}
		pcu_{13}		pcu_{33}	.	pcu_{i3}	.	pcu_{43}
	4	sc_{14}		.	.	.	.	sc_{44}
		pcu_{14}		.		.	.	pcu_{14}

A linear programming model to determine the cost-effective machine to process each operation of the component such that the total cost of manufacturing the component is minimized for a given volume of production say month of that component (1).

$$Minimize\ Z = \sum_{i=1}^{m}\left(\sum_{j=1}^{n_i} y_{ij}\left(sc_{ij} + v \times pcu_{ij}\right)\right) \quad (1)$$

Subject to

$$\sum_{j=1}^{n_i} y_{ij} = 1, i = 1, 2, 3, \dots, m$$

Where,

m be the component's total number of operations

i = 1, 2, 3... m, where n i is the number of machines that can process operation i.

The setup cost per unit of the operation i on its approved machine is sc ij. j = 1, 2, 3... m and j = 1, 2, 3,......, n i

The processing cost per unit of the operation I on its qualified machine is denoted by the symbol pcu ij. j = 1, 2, 3... n i and i = 1, 2, 3,.... m

v is the component's monthly production volume, for example.

If an operation employs a machine, then y ij = 1, where i = 1, 2, 3,..., m and j = 1, 2, 3,.., and n i.

= 0, i = 1, 2, 3,..., m and j = 1, 2, 3,..., n i if the operation i does not employ the machine j.

The goal function includes the sum of the setup costs and processing costs of the qualified machines chosen for each operation for the component's specified volume.

For i = 1, 2, 3...m and j = 1, 2, 3,...,n i, the constraint i in the constraint set selects just one machine from among n i machines to carry out the component's operation.

5 Illustration of model using sample data

Sample data is used in this section to illustrate the linear programming model for process planning of a component that was described in the previous section.

In Table 2, sample information for process planning is displayed.

Table 2 Process planning example data

			1	2	3
	Operation Number *i*		1	2	3
	Number of qualified machines (n_i)		n_1=3	n_2=2	n_3=3
Machine *j*	1	Setup cost	1000	1500	2000
		Processing cost per unit	500	400	700
	2	Setup cost	800	1300	2500
		Processing cost per unit	400	300	900
	3	Setup cost	1200		1500
		Processing cost per unit	600		450
	4	Setup cost			1750
		Processing cost per unit			600
Volume of production of the component per period say month (*v*)					6000

A linear programming model for the process planning model is as follows, and it is based on the data in Table 2 given above.

Minimize Z =1000* y11+500*6000*y11 + 800*y12+400*6000*y12 + 1200*y13+600*6000*y13 + 1500*y21+400*6000*y21 + 1300*y22+300*6000*y22 +2000*y31+700*6000*y31 + 2500*y32+900*6000*y32 + 1500*y33+450*6000*y33 + 1750*y34+600*6000*y34

Subject to

Y11+ y12 + y13 = 1
Y21+y22 = 1
Y31 + y32 + y33 + y34 = 1

Where,
y_{ij} = 1, if the operation I uses the machine j, i=1, 2, 3, , m and j = 1, 2, 3… n
= 0, if the operation I does not use the machine j, i =1, 2, 3 . . . , m and j = 1, 2, 3, …, n
v is the volume of production per month of the component and integer

The linear programming model of the processing planning problem's data in the format of LINGO software is presented in Figure 3. The result obtained from LINGO software are presented in Figure 4. Table 1 summarises the process planning issue based on the outcomes of the linear programming model depicted in Figure 4.

```
min= y11*1000+500*6000*y11 + y12*800+400*6000*y12 + y13*1200+600*6000*y13
     + y21*1500+400*6000*y21 + y22*1300+300*6000*y22
     +y31*2000+700*6000*y31 + y32*2500+900*6000*y32 +
     y33*1500+450*6000*y33 + y34*1750+600*6000*y34;
y11+ y12 + y13   = 1;
y21+y22          = 1;
y31 + y32 + y33 + y34    = 1;
@gin(y11); @gin(y12); @gin(y13); @gin(y21); @gin(y22); @gin(y31); @gin(y32);
@gin(y33); @gin(y34);
```

Figure 3 Linear programming model of the processing planning problem's data in the format of LINGO software

```
LINGO/WIN64 20.0.8 (17 Oct 2022), LINDO API 14.0.5099.185
  Licensee info: Eval Use Only
  License expires: 16 MAY 2023
  Global optimal solution found.
  Objective value:                              6903600.
  Objective bound:                              6903600.
  Infeasibilities:                              0.000000
  Extended solver steps:                               0
  Total solver iterations:                             0
  Elapsed runtime seconds:                          0.04
  Model Class:                                      PILP
  Total variables:                       9
  Nonlinear variables:                   0
  Integer variables:                     9
  Total constraints:                     4
  Nonlinear constraints:                 0
  Total nonzeros:                       18
  Nonlinear nonzeros:                    0
                                Variable           Value        Reduced Cost
                                     Y11        0.000000            3001000.
                                     Y12        1.000000            2400800.
                                     Y13        0.000000            3601200.
                                     Y21        0.000000            2401500.
                                     Y22        1.000000            1801300.
                                     Y31        0.000000            4202000.
                                     Y32        0.000000            5402500.
                                     Y33        1.000000            2701500.
                                     Y34        0.000000            3601750.
                                     Row    Slack or Surplus      Dual Price
                                       1         6903600.          -1.000000
                                       2         0.000000           0.000000
                                       3         0.000000           0.000000
                                       4         0.000000           0.000000
```

Figure 4 LINGO software's output from a linear programming model

Table 1 lists the outcomes of the linear programming model used to solve the process planning issue

Operation i	Value of y_{ij} which has value of 1	Machine selected (j)
1	$y_{11} = 1$	2
2	$y_{22} = 1$	2
3	$y_{33} = 1$	3
Total cost of the solution	Rs. 69,03,600	

6 Conclusion

Process planning is a vital exercise to minimize the cost of manufacture of components in companies. In this paper, the process planning problem has been dealt in two stages. In the first stage, a linear programming model has been presented for this problem by taking the following data.

i. Number of operations of the component (m) for which the process planning task is to be carried out.
ii. Number of qualified machines (n_i) to process the operation i, i = 1, 2, 3, …., m.
iii. Setup cost and processing cost per unit in the machine j of the operation i of the component, i = 1, 2, 3, . . . ,m and j = 1, 2, 3, . . . , n_i.

In the stage, the linear programming model of the processing planning problem considered in this paper had been solved using LINGO 20.0 software. Then the linear programming model as used in LINGO 20.0 and its results are presented.

The linear programming model presented in this paper becomes a handy tool for process planning, whenever a new component is introduced to reconfigure an existing product or that component is used in a new product.

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Thermal sensation models for environmental parameters testing

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Keywords: microclimate, thermal stress, thermal comfort, environment, thermal manikin.
Abstract: Currently, there are various complex models that are used to predict the thermal load, or thermal comfort of the employee with different scales for evaluating the feeling of warmth or of cold, with the help of which it is possible not only to speed up the evaluation of the thermal load but also to make it more precise. With the help of thermal manikins, it is possible to simulate human reactions to heat and humidity conditions. The article deals with the possibilities of using thermal manikins as a useful aid in measuring heat exchange between the environment and the human body, testing thermal stress, etc. These tools will then be available for use by the industry to develop more efficient thermal comfort systems.

1 Introduction

The text of the article is font type Times New Roman. The human body is surrounded by a microclimate, which is the result of its convective release of heat in the environment. In industrial operations, workers are exposed to various extreme microclimatic conditions. Currently, there are various complex models that serve to predict the employee's thermal comfort with different scales for evaluating the sensation of heat/cold. Because these models work with different parameters, there is no uniform model that can contain all types of activities and clothing that directly impact thermal well-being.

The real conditions affecting people at the workplace can be simulated in thermal chambers. These climatic chambers are specially designed and equipped for this method of simulation. Human reactions can be simulated using thermal manikins, which are a useful aid in measuring the heat exchange between the environment and the human body, testing thermal stress, etc. Several methods and calculation models are used to assess thermal comfort. Models of the human body are so-called thermal manikins. These devices can be applied primarily when testing the properties of clothing or the safety of specific products such as protective equipment and clothing for extreme conditions, but also in the design and applications of HVAC systems, etc.

Using thermal manikin in climate chambers with different air temperatures, it is possible to simulate the release of heat from the human body. Various techniques are used for measurement and visualization (monitoring of airflow, thermography, anemometry, etc.).

2 History of thermal manikins

In 1939, General Electric built the first-ever thermal manikin made of copper to test an electric blanket. Subsequently, figures were produced with the main purpose of testing the protective clothing used by the US military (Figure 1, Figure 2). In 1941, researchers - Gagge, Burton and Bazett developed a unit of thermal resistance that is used to describe the insulating value of clothing (clo). Since then, instrumental studies of man, clothing and his environment have been used more and more.

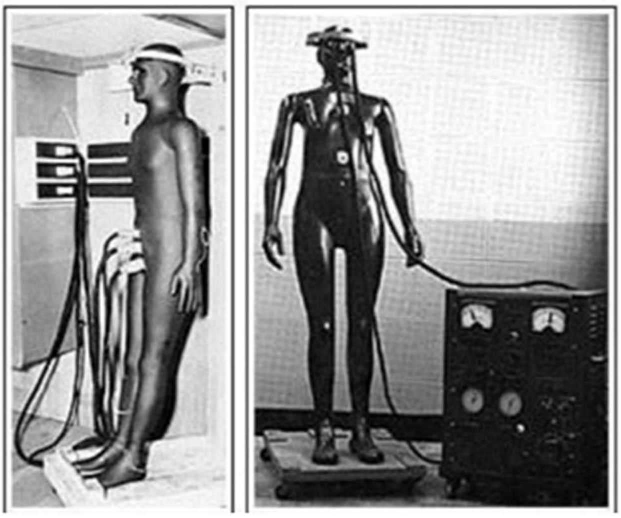

Figure 1 First models of thermal manikins [1]

Copper was the material used to make the manikin. The prototype of the manikin still had limited mobility [1,4]. The subsequent development changed not only the appearance but also the type and material of the manikin. From one segment it gradually became a multi-segment. Elements such as a manikin with a sweating system, a breathing system, etc. were gradually added.

In 1964, copper was abandoned and manikins began to be constructed from aluminium. Next, in 1967 were made

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the first manikins from plastic materials in Denmark. In 1973 there was a manikin that could move and in 1996 it could even breathe. Later, he also performed realistic movements that employees perform during work.

Figure 2 Thermal test protective clothing manikin [1]

The material from which the manikin was made also changed. The breakthrough occurred during the millennium when manikins made of porous materials and metals began to appear. The type of regulation has also undergone progress, while the first such manikin worked on analogue regulation, currently, digital transmission of the obtained data is used [1,6].

Currently a thermoregulation manikin with a sweating system is used in the industry. The automotive application, thermal manikins appeared in the 1980s, and they have been in constant development ever since [10].

In addition to experimental methods, numerical methods are also used for indoor microclimate research. These are usually Computational fluid dynamic (CFD) techniques. In both experimental and numerical methods, thermal conditions must be related to the thermal sensations of the interior space user [8,11].

3 Models of the thermal manikins

The thermal manikin is a special device that matches a person’s appearance and is used to evaluate the thermal load, the so-called thermal comfort or discomfort. With the help of these manikins, it is possible to simulate the transfer of heat between the human body and the working environment. There are different types of human models or models of parts of the human body with different uses [1,2,7]. To a certain limited extent, they can also be used for the purpose of testing human physiological reactions. Among the most famous models used to determine the thermal comfort of a person are:

- Fanger’s model,
- Wissler's dynamic model,
- Stolwijk's model,
- Gagg's 2-node model,
- Fiala's model,
- Tanabeh's dynamic model,
- Kohri and Mochid model,
- Fiala's multi-node model etc.

Currently, there are approximately 100 manikin models that are used in determining the thermal-humidity microclimate, for environmental and clothing testing (Figure 3).

Figure 3 ANDI manikin for clothing testing [13]

The most frequently used manikin is the Newton model [9]. This model consists of 34 heated 34 zones and is made up of parts such as the head face, chest, abdomen, arms, forearms, hands, hips, calves and feet (Figure 4).

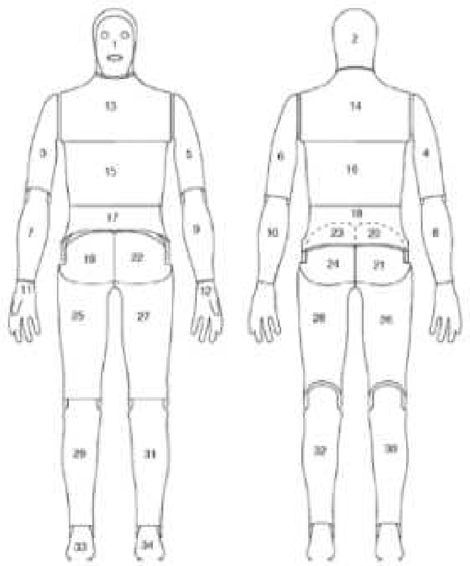

Figure 4 Newton model with parts of the human body [13]

The Newton model is interconnected with software, which includes physiological models of thermal comfort. The systems that the manikin contains make it able to simulate a person, i.e., j. sweating, walking, breathing. The manikin even has an adjustable breathing system. These conveniences cause more efficient monitoring of thermal comfort. The data obtained from the manikin is evaluated using special software. System innovations are becoming more and more evident not only in software but also in manikin models. Future software variants will also enable the connection of the classic model of Newton's manikin with virtual reality. This connection will allow any simulations to be performed [13].

3.1 HVAC automotive manikins

The use of thermal manikin is very broad. However, it is mostly used in testing the thermal insulation of protective clothing. When determining the insulation of clothing, the main monitored parameters are moisture evaporation resistance and thermal insulation.

The above-mentioned factors form the basis for the thermal insulation of clothing and are influenced not only by the type of material used but also by the heat and humidity of the environment. The requirements for measurements of thermal insulation of clothing, resistance to moisture evaporation is established by the relevant stan. Advanced thermal manikins for seat testing are shown Newton manikin model and ADAM manikin (ADvanced Automotive Manikin). The values that are obtained are subsequently used for the optimization and modeling of ventilation and air conditioning devices in the interior spaces of buildings.

The danger of heat also often arises in cases of fire. Since a human cannot be used for tests or measurements in these conditions due to the potential risk, manikins are used which are designed to replace humans. Because the surfaces of the manikins (shells) are significantly different compared to human skin, sensors are implanted in the manikins and a related mathematical model is built to simulate the skin.

Thermal manikins are also a key element in the development of technologies based on the Heating, Ventilation and Air-Conditioning system (HVAC) to achieve a safer and more comfortable working environment. In uncomfortable hot ambient, thanks to the thermoregulation system, the human body starts with vasodilatation and sweating, trying to prevent a rise in internal body temperature. Since these mechanisms are of limited capabilities, to prevent the further rise of body temperature and to avoid the risk of hyperthermia, it is necessary to make the ambient comfortable by cooling or to ensure the way to release the heat from the body.

The manikins are available in different materials and designs. Thermal manikin is often used in the automotive industry. Since they help in the development of HVAC technologies, they find their use for the evaluation of heating/air-conditioning equipment in passenger cars, trucks and various other means of transport.

The automotive HVAC manikin features a system that includes a carbon epoxy body mould with surface-mounted sensors that measure air velocity, temperature, radiant heat flux, and relative humidity. The sensors are protected to ensure that the manikin is not damaged during loading and positioning [3,4,10]. The HVAC manikin for automobiles ("Automotive HVAC Manikin") is designed so that it can be easily inserted into any vehicle. The hands are in the shape of gloves with a curved grip, the design of which allows for proper positioning on the steering wheel. Their shape does not affect air movement but allows airflow similar to a human grip/fist. The back of the thighs is flattened to simulate realistic airflow [2,4,5].

The microclimate conditions and thus human thermal sensation as well, are dependent on air temperature, air velocity, relative humidity and mean radiant temperature. Automotive manikins are used to test the thermal comfort of passengers and the thermal and humidity parameters in the cabins of vehicles HVAC systems (Figure 5).

Figure 5 Newton automotive HVAC manikin [12]

Any improvement of the HVAC system and optimization of the thermal environment in the cabin are potentially associated with an increase in thermal comfort in the vehicle and a reduction in heat load and greenhouse gas emissions, including the total energy consumption of the vehicle [2,12].

The requirement to provide a comfortable interior space in the vehicle is often met at the expense of energy requirements. The energy demand of the air conditioning unit requires a lot of attention, especially in the case of electric cars and hybrids, when saving electricity affects the range of the vehicle. Among the biggest challenges of the HVAC system of vehicles and car cabins is quickly and efficiently cooling the interior of a vehicle parked in the sun on sunny summer days. Incorporating the solar load as a source of heat into the CFD analysis was difficult until recently, but there has been a shift in this direction and many current CFD software allows calculations taking the solar load into account.

4 Conclusion

Today's applications of thermal manikins primarily consisting of the thermal insulation properties of clothing or thermal conditions in building interiors. The use of climatic test chambers with thermal manikins is one of the new trends in HVAC design. By applying these modern technologies, it is currently possible to create a complex model of thermal comfort in the interior of buildings or the interior of the driver's cabin even before the actual HVAC installation takes place. Human thermal manikins with a high degree of sensory spatial resolution, local thermoregulatory responses including sweating, fast time response and feedback for continuous response and adaptation to the thermal environment like a human will be increasingly available for industrial use as well as for the development of more efficient thermal management systems. comfort. Numerical thermal comfort models and thermal manikin are becoming thermal comfort assessment tools that can accurately predict human physiological and psychological responses in real and simulated non-uniform transient thermal environments.

Analytical and simulation computer programs in connection with mathematical models of thermal comfort and human thermal models allow, compared to experimental methods, to provide a more complex picture of microclimate conditions with the possibility of quick and inexpensive solution design.

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Significance of employee education for the development of the company

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Keywords: employee education, company education, training program, training methods.
Abstract: Education is a process during which new knowledge, skills and attitudes are acquired and developed. The goal of employee education is to ensure qualified, educated and capable workers, necessary to meet the needs of the organization. In order to achieve this goal, employees must be willing to learn and able to take responsibility for their own learning. Education thus becomes a lifelong process. Without the development and training of employees in companies, these companies may lose flexibility, quality and loyalty of employees in the near future, as well as the interest of customers. That is why this article focuses on the importance of education through which business is developed. The following theoretical overview is devoted to the importance of employee education in companies. Significant terms are defined and the meaning of company education for the present and future of the company. The next part is devoted to the system of company education itself, its phases, methods and possible training programs.

1 Introduction

The meaning of education can be different for individual organizations. Each company attaches different importance to the development of education, depending on how important the quality of human capital is for the functioning of the organization's system and how large the financial means are for the implementation of these activities. If a company decides to educate its employees, the company's goal becomes identical to the goals of various other companies which means the same competitiveness in the industry.

According to Valent, education is a process where various competencies are acquired based on the acquisition of all kinds of knowledge, attitudes, skills and new experiences [1]. Adult education is a process of purposeful and systematic mediation, consolidation and acquisition of abilities, habits, knowledge, social forms, value attitudes and actions and behaviour of persons who have completed school education and vocational training and entered the labour market [2].

The present time is full of new information, therefore the continuous development of employees is the basis for ensuring the efficient functioning of the organization. Employee development, as part of an organization's overall human resource strategy, means the useful contribution of workplace learning experiences to the organization so that performance can be improved, work goals can be achieved, and so on, through increasing people's skills, knowledge, learning abilities and enthusiasm. at each level, the continuous growth of the individual can be ensured in the company. Employee development must be part of a broader business strategy, aligned with the company's mission and corporate goals.

Adult education as a subsystem of education is also a supersystem of corporate education. Every employee has the right to obtain the necessary qualifications and adequate education for work in the profession, but also the knowledge necessary for the development of their own personality. Achieving the desired level of education is a continuous long-term process with a number of mutual and continuous connections during the active period of employment.

2 Education in industry

Companies with a positive philosophy of education understand the fact that the development of human resources, through education, is the best investment, even if it is very difficult to clarify the return of these investments. Employee training can be characterized as a permanent process in which there is adaptation and change of work behaviour, level of knowledge, skills and motivation of the company's employees by learning based on the use of various methods. As a result, the gap between the current competencies of employees and the requirements placed on them is reduced.

Employee training goals are specific variables that no company should underestimate when it comes to a successful training activity. The goals define what employees need to be taught, what skills and knowledge they should acquire, or at what level they should master them for effective work performance [3]. Setting goals can be easier when using the SMART method. SMART is an abbreviation of terms that define goals:

- S (specific),
- M – (measurable),
- A – (accepted, activating),
- R – (realistic),
- T – (timed).

The goals of education within the organization have several connections and can result from a specific situation [4]. In order for the company to be successful in the market, top managers should contribute to the proper course of the educational process, support the development of employees, formulate the company's education policy and be participants in educational projects themselves. Immediate superiors have the task of supporting the development policy and recognizing the educational needs of employees in the company. It is often a lecturer or mentor of subordinates and often replaces an external trainer. In order for immediate superiors to replace an external trainer, they need to develop their competencies and also need to be supported by senior management [5]. The most frequently used sequences are:

- educational goal – it is linked to a specific educational event, it is specific knowledge, skills or behaviour that the participants should acquire after the end of the given program,
- performance goal – it is tied to the main task and has the form of a vision that the educational activity is able to fulfil in the long term,
- enabling goal - just like the educational goal, it is linked to a specific educational program and defines the level of knowledge that participants should be able to master at the end of each partial stage of the educational process [6].

An important element of the educational process is also the motivation for workers to learn and thereby increase their potential. Every competitive company should have the motivation of employees in education ranked at the top of the list of priorities. The benefits of education are manifested gradually, over different periods of time. Some can be evaluated already during education, some only after it ends, and some will become apparent only after a longer period of time [7]. The cycle of systematic training of employees itself has several phases. The first phase is the identification of training needs, which deals with the analysis of data and information of specific companies. The second phase follows the training planning phase, which mainly deals with the budget, and time schedule, which employees will be covered by the training, areas, content and training methods. The third phase is the implementation of the education process. Employee training is costly for the company, and it is necessary to find out whether the set goals have been achieved and whether the chosen methods and training tools have proven themselves. Therefore, the next and at the same time the last stage is the evaluation of education. In this phase, we obtain valuable information that we will use in the next cycle of systematic education. Business education should thus take place as a constantly repeating cycle (Figure 1) [8].

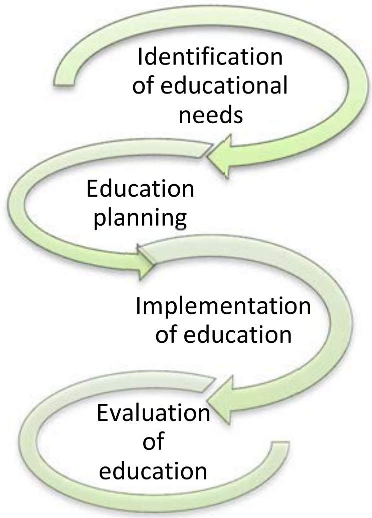

Figure 1 Framework of systematic training of employees [7]

According to Koubek, the need for employee education can result from the evaluation of the employee's work performance, the quality of products or services, the use of resources or working time, and the like. So there are many sources of information that can be used. In practice, a narrower or wider range of data is analyzed, which is obtained from the information system of the given company or through a special investigation [9].

2.1 *Training methods*

The main goal of employee education and development is to provide the necessary knowledge and information, mainly of a professional nature, to perform certain activities. And by training in human resources management, which increases the value of production capital, it is necessary to develop mainly human abilities and creativity by the most effective means, including education. The successful implementation of the educational process depends very much on the correctly chosen method of employee education. Educational methods are primarily divided into two main groups [10]:

- On-the-job training - this method acquires and acquires the knowledge, skills and abilities that are necessary for improving work performance. The application of training methods at the workplace occurs during the normal course of the work process, when employees can train in groups, but especially individually during the performance of work.
  - Instruction, coaching, mentoring, counselling, assisting, job rotation, and others.
- Off-the-job training – this method is generally used to train executives or specialists or technical staff.
  - lecture, lecture combined with discussion, demonstration, case studies, workshop, brainstorming, simulation and others.

Methods are an important tool of the educational process, and that is why it is necessary to know how to choose and use them in such a way that they best reflect the needs of the given company [11]. The choice of methods is conditioned by various factors, which can be seen in Figure 2.

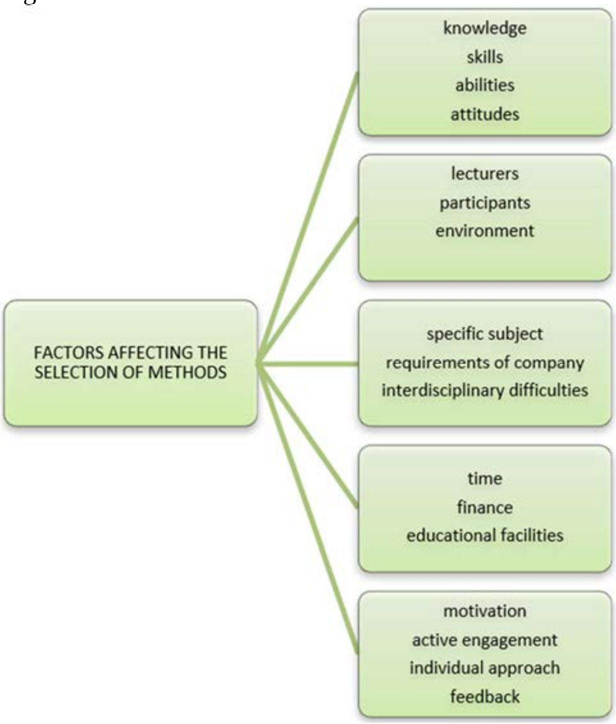

Figure 2 Factors influencing the selection of methods [11]

Other forms of education such as instruction, coaching, mentoring or e-learning are also used in practice. The last mentioned method, e-learning, has become popular in recent years, especially during the pandemic crisis. It is an online method that is the connecting point between on-the-job training and off-the-job training. It uses the computer's ability to help in the continuous formation of qualifications and requalification of people, regarding new processes and procedures [12]. It has an important role in distance learning in the field of vocational education or higher education provided by some institutions. Most computer-aided learning systems direct learners to study text on a screen. It is also possible to use the Internet or intranet. It is a good alternative if the employees are far from each other, it can be combined with electronic coaching. The disadvantage is that the organization of e-learning activities requires investments, and learning only through e-learning requires considerable self-discipline from the participant [13]. A good alternative is combined education, that is, combining e-learning with learning in groups that are related to the company. Each of the methods mentioned above is something specific, and e-learning is not just one, it has three types, which are:

1. Independent or separated e-learning, when the participant of the educational program is connected only to himself and is not coordinated in any way by a lecturer, consultant or moderator;
2. Live e-learning, when the learner meets with a lecturer, moderator or consultant and his work process is coordinated by him, but each of them is located in a different place;
3. Collective e-learning, when there is cooperation between several e-learning participants using chat, discussion forums, etc., where they exchange and sell the necessary information and knowledge [14].

If the company decides to combine one of the educational methods in the workplace or outside it and e-learning, it is necessary to evaluate which type of e-learning will suit the chosen method the most and then use it [15].

2.2 *Employee training program*

The training need identification phase precedes planning. In organizational education plans, needs are identified, priorities are determined, and based on these, proposals for programs and budgets are formulated and it is determined which employees will be covered by the education. The individual sub-plans for the development of human resources reflect the decisions of managers when creating work potential. The sub-plans also include an employee training program, which should ensure alignment of the qualification structure of the employees with the goals and tasks of the company [16].

The education program can be characterized as a comprehensive program of determining, fulfilling and verifying the goals, content, methods and forms of the educational process, its evaluation, organization and management; the educational program can be divided into modules. An educational program module is understood as a separate, comprehensive, binding, time- and content-related educational unit of an educational program [17].

The content of the employee training program is the definition of training areas, the number and categories of employees who will be involved in training, the methods and time schedule of training entities that will take care of the training, as well as the corresponding amount of financial costs for training. Individual training programs take into account the specific needs of a given category of employees. Designing the educational program [18]:

- Starting points for the preparation of the educational program;
- Needs identified in the stage of educational needs analysis;
- Human resource management strategy;
- Limitations and resources;
- Preparation of the educational program;
- Determination of the target group of education participants, formation of study groups;
- Defining the content of the educational program,
- Choice of education methods;
- Selection of subjects for program implementation;
- Selection of lecturers;
- Preparation of literature and didactic aids, determination of the time range of education;
- Choosing a place of education;
- Refinement of the budget;
- Preparation of evaluation questionnaires, other services – accommodation, food and transport;
- Implementation of the program.

Education can be carried out in the company directly at the workplace during the performance of work or outside the workplace on premises intended for teaching. Realized externally, i.e. outside the company, through various educational institutions [19]. Sometimes a combination of the previous two options can be used, when the training is carried out in the company and external lecturers join the training program. If the company decides to train employees from an external organization, it should be selected based on the selection process according to the following criteria [20]:

- Previous experience of the company;
- References from other companies about the level and conditions of the educational activities provided;
- Price level of education;
- Possibility of obtaining a course completion certificate;
- The possibility of cooperation with an educational organization in the design of the educational program, as well as in the application of acquired knowledge in practice.

3 Conclusion

The topic of education is very current and will be even more important in the future. Possibilities and development of education in companies should be one of the priorities because this is the only way the company develops in direct proportion to new technologies. Every industrial enterprise should therefore create regular educational projects, and educational programs and, more importantly, regularly evaluate them and obtain reports on which part or area of the enterprise has deficiencies, or which group of employees has an education deficit.

Another important stimulus for employee education is the characteristic peculiarity of modern production. Workers are constantly required to improve and develop in order to be able to use new computing techniques and understand technological processes. In addition, corporate education should use new forms and methods for working with the latest technologies, the development of which is a crucial factor for improving production efficiency. The comprehensive education system meets the needs of production and ensures the development of each worker throughout his working career.

Corporate education is not an easy topic and its implementation is an expense that is not always optimally returned, therefore it must be carefully planned and suitable forms of corporate education must be selected. As a generally valid principle in the field of company training, which we want to do efficiently and with high quality, it is important that the company knows why it wants to train, what exactly it wants to teach the workers, who it wants to train and which of the employees needs training the most. It is therefore obvious that if a company wants to survive on the market, it is important for it to invest in the education and development of its subordinates, as investments in human capital are a basic prerequisite for increasing the efficiency, performance and competitiveness of the entire company.

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3D printing methods used in engineering

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Keywords: 3D printing, FDM, ColorJetPrinting, DOD-PolyJet, SLS.
Abstract: 3D printing as a functional Rapid Prototyping tool has been used for years, and along with the advancement of engineering technology, 3D printing technology is also developing and improving. This technology has not found representation only in the engineering industry, but across industries such as healthcare, construction, etc. In the end, I also present specific cases of the use of 3D in practice. From the most basic 3D printing with simple technology, several kinds of printing methods have evolved. From the point of view of simplicity for the novice user, the technology is FDM (Fused Deposition Modeling). With this 3D printing technology, the process of applying a thin layer of molten filament to the printing surface is used until a complete model is finally created. FDM is also characterized by the use of a wide range of materials, such as ABS, PLA, HIPS, PET-G but also wood or copper. Other methods I will describe are SLA, SLS, DOD-PolyJet. These are less available for use and acquisition by the average user, but are increasingly sought after, due to the expanded printing options. In the end, there is also an example that we processed for a company in the field of assembly.

1 Introduction

The basic principle of 3D printing is "additive manufacturing", which in practice means that we do not have a large block of material at the beginning, but printing begins on a clean substrate by gradually applying the material layer by layer as precisely as possible, according to the requirements for strength, stiffness and thermal properties, or resistance to influences such as chemicals, water, sunlight, alcohol, etc. According to these requirements, the material (filament) and the method of creating the model are subsequently chosen. The way the printer applies the material is layer by layer in 3D space. It is then moved horizontally by the next layer until a complete 3D model is created. Even though individual printing methods differ from each other, they all have one thing in common: applying material layer by layer. Therefore, it is necessary to modify the 3D model (most often in STL format) in the software before printing, dividing it into several thin layers forming the entire object. The thickness of the layers best corresponds to the quality of the model. The thinner the individual layers, the more accurate the print quality, and the transition between layers is minimal. So printing in the smallest possible layers appears to be the most optimal quality, but it has its limitations. The hardware itself has limits on how thin a layer it can create. If the software allows even extremely thin layers, we waste a lot of time in the area of dividing the model into layers, because the software has to cut the model into many layers. The printing time itself is also significantly extended because it takes longer to create one layer and at the same time a larger number of layers must be created. These shortcomings and limitations in terms of quality and time are minimal against the advantages of 3D printing. It is necessary to find the most suitable type of technology, determine the required properties of the print, choose the material accordingly and ultimately find a compromise between speed and precision of printing [1-4].

2 Fused Deposition Modeling - FDM

The principle of this method consists in melting the material. The material entering the process is the filament, which reaches the print head, where it is heated to the required melting temperature. Subsequently, it is printed with the help of a nozzle, which slowly applies the individual layers to the printing pad (Figure 1).

The main advantage of this technology is the use of a very large number of types of materials for this type of printing. Another of the advantages and positives of this type of printing is the creation of a minimal amount of waste. The disadvantage is the lower quality of the final surface of the material, which is indicated by the minimum height of the layer during printing, which is around 0.25 mm [1-4].

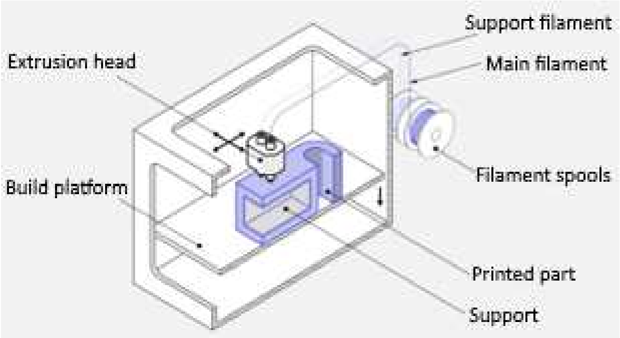

Figure 1 Fused Deposition Modeling

3 Stereolithography - SLA

SLA 3D printing works by first placing a build platform in a tank of liquid photopolymer at a distance of one layer height from the surface of the liquid. The UV laser creates another layer by selectively curing and solidifying the photopolymer resin. During solidification, part of the photopolymerization process, the monomeric carbon chains that make up the liquid resin are activated by UV laser light and become solid, forming strong, unbreakable bonds between them. The laser beam is focused in a predetermined path using a set of mirrors, called galvos (Figure 2).

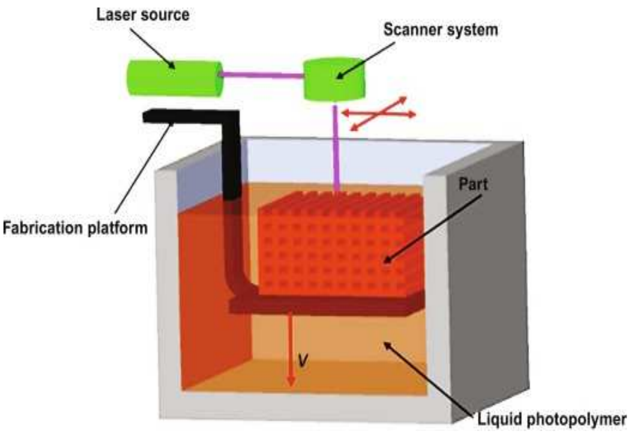

Figure 2 Method of stereolithography

The main advantage of this method is good printing accuracy. This method is more time-consuming to prepare and complete, as it is necessary to remove supports as mentioned above, which we call postprocessing [1-4].

4 Selective Laser Sintering - SLS

The SLS method uses a combination of laser and powder for printing, which is dispersed in a thin layer on top of the platform inside the build chamber. The printer preheats the powder to a temperature slightly below the melting point of the raw material, making it easier for the laser to raise the temperature of specific areas of the powder bed as it follows the model to solidify. The laser scans a cross-section of the 3D model and heats the powder just below or directly to the melting point of the material. This mechanically joins the particles together to form one solid part. The unfused powder supports the part during printing and eliminates the need for special support structures. The platform is then lowered one layer into the assembly chamber, typically between 50 and 200 microns, and the process is repeated for each layer until the parts are finished (Figure 3).

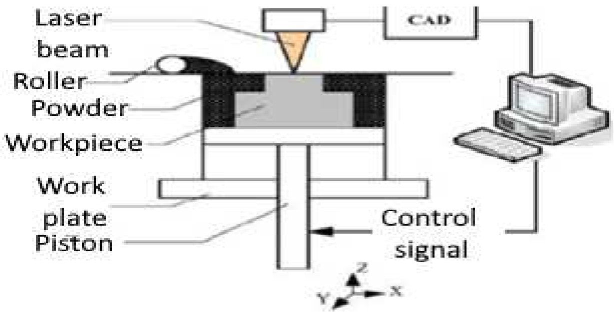

Figure 3 Selective Laser Sintering

With the help of this method, it is possible to print a fully functional model, and thanks to the diverse selection of materials, it is possible to choose from a wide range, such as - ceramics, polycarbonate, metal, nylon, etc. This one is not compact for home users, as its dimensions are a bit larger due to the built-in trays ready to feed different types of material directly from the printer part [1-4].

5 DOD - PolyJet, MaterialJetting

PolyJet 3D printing technology is quite similar to a regular inkjet printer that prints on paper. In this method, 2 types of material are used: construction material, which forms the basis, and support material, which ensures stability during the printing process. For the help of the print head is the material applied to the printing substrate. Thanks to the large number of nozzles that the nozzle head has, it is possible to apply a larger width of material at once without problems. These nozzles apply a small amount of material in the form of drops, which, after being applied to the material, are immediately cured with the help of a UV lamp located in the printer near the print head (Figure 4). The main material is photopolymer, and the supporting material can be removed with the help of water, as well as with SLS technology, or it can also be removed mechanically. This PolyJet technology gives us high-quality printed and subsequently cleaned parts. Where with FDM technology the minimum layer is 0.1, this is the smallest possible height at an incredible 0.014 mm. Since it can print a wider layer of material, it is therefore much faster than SLA technology. The width of the printed layer can be adjusted using the print head, which can be changed to the desired size. Last but not least, there is a wide range of materials and colour options to choose from [1-4].

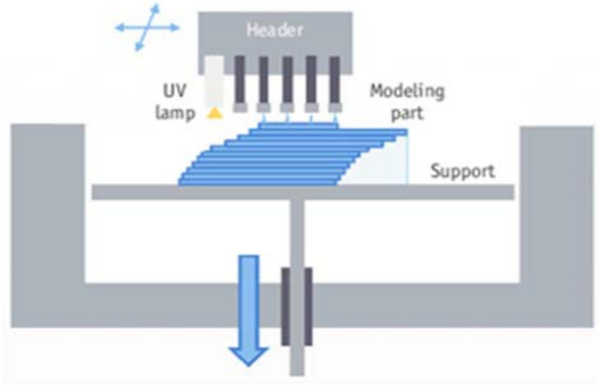

Figure 4 PolyJet

6 Colour Jet Printing, Binder Jetting

Colour Jet Printing (CJP) is an additive manufacturing technology with two main components: a core material and a binder. The core material is applied with a roller in thin layers to the construction platform. After each layer is applied, a coloured binder is selectively ejected from the inkjet print heads and this causes the core to solidify. The build platform is lowered to allow each successive layer to be laid out and printed, resulting in a full-colour three-dimensional model (Figure 5).

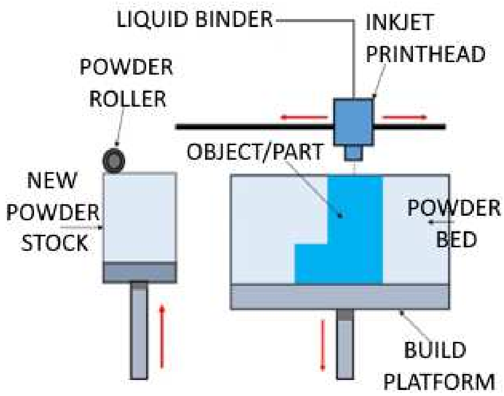

Figure 5 Colour Jet Printing (Binder Jetting)

As with the DOD method, one of the advantages is fast printing with the help of a wide print head that can apply a wide layer of the binder. The printed models using this method do not have high strength and therefore it is necessary to modify them quite often, that is, to use the so-called postprocessing [1-4].

7 Conclusions

This article describes 3D printing technologies. 3D printing is becoming an integral part of both small-scale production and large enterprises. A big benefit is their purchase price, of course, it depends on the size of printers, 3D printing technologies, and the use of different types of materials and software for converting to gcode format file. another benefit is the simplicity of model creation, as the software converts the model in .stl format to .gcode and calculates the extruder path itself, if necessary, it is possible to configure the properties of the printer as well as the model in the software. The disadvantage of 3D printing is occasional imperfections, as, for example, an FDM printer works at the micrometer level.

3D printing has also found its place in the field of aviation. Maintainers from the 60th Maintenance Squadron and 349th Aircraft Maintenance Squadron, along with engineers in Georgia, are using 3D printing in maintenance as a rapid means of creating faulty or damaged components.

Improving properties and their degradable footprint is a challenge for industrial companies. The KIMYA company disclosed an analysis of the material used in FDM printing, more precisely 3D PETG filaments. The report shows that the use of recycled PETG filaments helps reduce CO2 emissions by 35% compared to standard PETG filaments.

Art and design are pushing the boundaries with 3D printing. In the last good, 3D printing is used more and more often by fashion designers or artists. An example is the Texas project Sunday Homes, where reconstruction is planned using 3D printing.

In addition to improving patient outcomes, the medical device industry could potentially use 3D heart replicas for testing.

Engineers at the Massachusetts Institute of Technology (MIT) have devised a way to 3D print a replica of a human heart, which could have a significant impact on personalized treatment for people with heart problems. The engineers behind the discovery hope it will help doctors tailor treatments to the specific shape and function of a patient's heart. 3D printed hearts are soft and flexible, and researchers can manipulate them to mimic a patient's ability to pump blood. The process of making one of these 3D copies of the heart begins by converting medical images of the patient's heart into a three-dimensional computer model [5-9].

Mr. Tay Yi Wei Daniel at the Journal of materials processing technology states that 3D printing of concrete can be used to build many complex structures. However, due to its material properties in the fresh state, it is difficult to build overhanging structures without support. To unleash the true potential of concrete 3D printing, a support structure is needed to support any protruding fresh material that is usually removed during post-processing. This study demonstrates the feasibility of adjusting print parameters to print the main structure and the supporting structure using a single type of building material [8].

Ramezani, Hamed in the study used multiphysics simulation to determine the potential printability of chitosan hydrogel as a desirable biomaterial used in tissue engineering. In the simulations, the flow was assumed to be laminar and two-phase. Furthermore, the influence of different speeds and viscosities in extrusion-based chitosan 3D printing was investigated [7].

Our result of using 3D printing specifically with FDM technology is the design and realization of a pusher model, for a company that had high losses when gluing cardboard boxes and the production of a new pusher from the company would have a long payback period. That is why the company chose 3D printing technology. The pusher is in the form of a prototype and is being tested directly in the company.

Another use is the processing of a request from a company that needed a grid for a filter device with flexible properties, where the 3D print is already directly introduced in production and meets the predetermined requirements.

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Design of an automated plastic bag packaging machine

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Keywords: plastic bags, prototype, packaging, machine design.
Abstract: Thin plastic bags are common in Vietnam's sweets and food stores. Currently, due to the need to preserve dried goods, the majority of these items will be stored in fully sealed plastic bags. In order to improve package efficiency, design, and eliminate packaging errors, a completely automatic packaging machine is required to assure safety and cleanliness, enhance performance, and enhance the aesthetics of packaging designs. The study provided an approach for designing a prototype of plastic bag product packaging. Use the SolidWorks to design, analyse, and select materials based on machine concept. Then, an electrical and pneumatic system was constructed, followed by the fabrication and testing of a prototype to demonstrate the validity of the model.

1 Introduction

Thin plastic bags are common in Vietnam's sweets and food stores [1,2]. Currently, due to the need to preserve dried goods, the majority of these items will be stored in fully sealed plastic bags [3,4]. In order to improve package efficiency, design, and eliminate packaging errors, a completely automatic packaging machine is required to assure safety and cleanliness, enhance performance, and enhance the aesthetics of packaging designs [5,6]. This topic combines numerous needs for an automated packing system. The packing machines function precisely, swiftly, and in the correct quantity and volume. Consequently, decreasing the loss of raw materials, thereby minimizing expenses. Packaging machines have been in Vietnam for a very long time; the majority of them are very advanced foreign machines; however, the cost of acquisition, maintenance, and operation is considerable [7,8]. Every day, the demand for packing dried goods for distribution on the market grows. The primary objective of the study is to design a product packaging machine system. Utilizing Solidworks software to design, test, and pick materials for details based on machine design theory, then, a PLC system is selected for machine operation design [9,10]. This machine was designed to increase worker productivity and enhance job efficiency.

2 Methodology

2.1 Plastic packaging machine overview

Product packaging machine refers to a packaging machine that is automatic in the production process, automatically packing, automatically measuring, weighing, measuring, and automatically closing with the highest degree of precision [11,12].

Bring efficiency to production and complete packaging. Human effort is used to replace manual product packing with packaging machines. The packing of food and other items is facilitated and accelerated by production assistance. Currently, all industrial and agricultural products are packed. In addition to preserving the goods, the packaging must also represent the brand and prevent counterfeiting.

2.2 Working principle

Figure 1 shown the preliminary design of the machine. The two most important parts of the machine are: container (3), welding rod (6). Hydraulic cylinders facilitate machine motion, The mechanism operates in stages: (1) click the Start button on the cylinder (2) to release it, and (2) activate the suction. Suction head sucking bag while cylinder (2) continues. The slider (1) transports the mounted mechanism into the weighing and packaging area. Cylinder (2) emerges, switches to the opposite side suction, and returns. The bag's mouth has been opened. The silo is unlocked by cylinder (3), the material is discharged into the bag, and the weight is measured by cylinder (7). When sufficient weight has been measured, cylinder (3) closes the silo discharge door. As the second cylinder (2) emerges, compress the bag's mouth. The extraction of cylinder (5) brings the welding mechanism into the packing area. Welding commences after the clamping cylinder (4) clamps two rods (6) with wire attached. At the conclusion of the welding process, cylinder (4) releases the clamp, cylinder (5) returns the mechanism to its original position,

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and cylinder (6) closes the two suction valves. The cylinder (2) and slider 1 return to their initial positions.

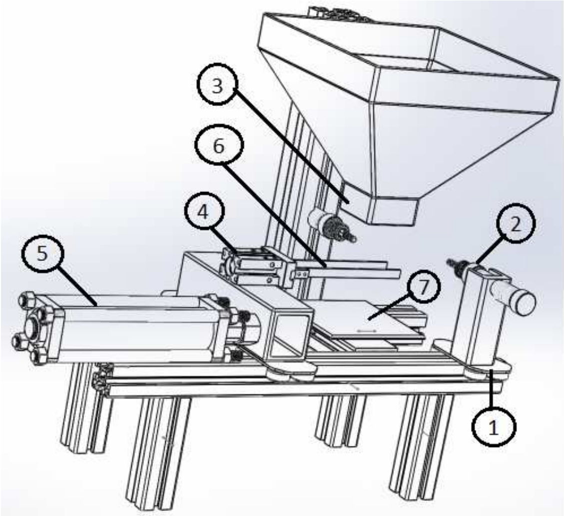

Figure 1 Overview of the packaging machine

2.3 System requirement

Table 1 summarizes the values used in the current work based on actual packaging requirements in Vietnamese manufacturing facilities for bags of dimension 3x4 with a maximum weight of 1 kilogram.

Table 1 System requirements

	Parameters	Requirements
1	Execution time of each cycle	< 60 second
2	Execution time for each step	< 20 second
3	Time delay	< 100 ms
4	Suction pressure	< - 0.03 Mpa
5	Bag size	3x4 cm
6	Mass product	0 – 1 Kg
7	Tolerance	0 – 1 Gram

2.4 Mechanical frame of machine

A machine frame must be robust and simple to attach and fasten with other components. Regarding bearing, it must be robust and rigid enough to support the weight of other details, primarily bending. Table 2 shown the mechanical properties of the 6063S aluminum employed in this study. The frame is constructed using aluminum shapes as shown in the Figure 2.

Table 2 Material properties of frame

Mass Density	Poisson's Ratio	Tensile Strength	Yield Strength
2700 kg/m^3	0.33	90 Mpa	50 Mpa

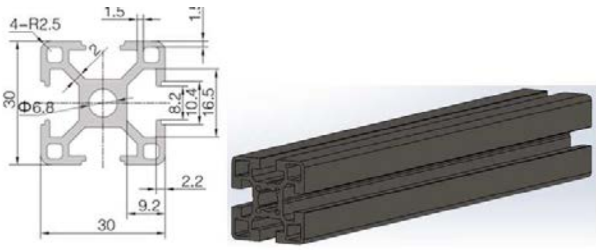

Figure 2 Shaped aluminium dimension

Other machine elements attached to the frame are estimated to weigh 5 kg. Figure 3 displays the results of a strength test performed on the frame using the Soliwork software. After ensuring the frame's durability, a prototype is built.

Figure 3 Frame of machine

2.5 Design electrical system

As seen in Figure 4, the system employs a Mitsubishi FX1N-60MR PLC with 36 Digital inputs and 24 Digital outputs; the PLC's power supply can be set to either220V.AC or 24V DC. Group of nine pneumatic valves DV3220 with DR100-5 suction wire were used.

Figure 5 shown the Display interface, the control panel mimics that of an external hardware controller. Output statistics and system error reports are also displayed. The monitor clearly displays the current program step, PLC error reporting, and output data. The test screen contains cylinder control buttons that display the operational state of the cylinder.

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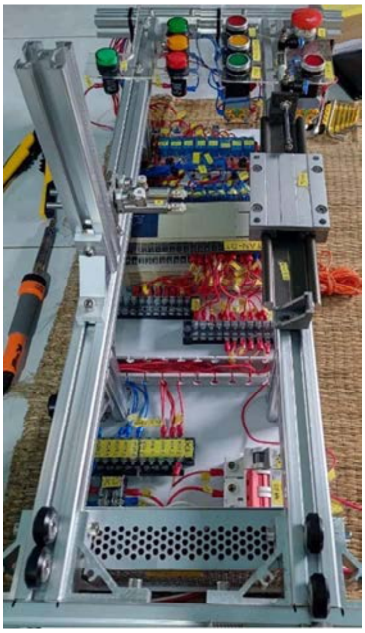

Figure 4 Electrical system

Figure 5 Display interface

3 Results and discussion

Figure 6 depicts the construction of a basic, inexpensive prototype for system testing, with components made from readily available materials.

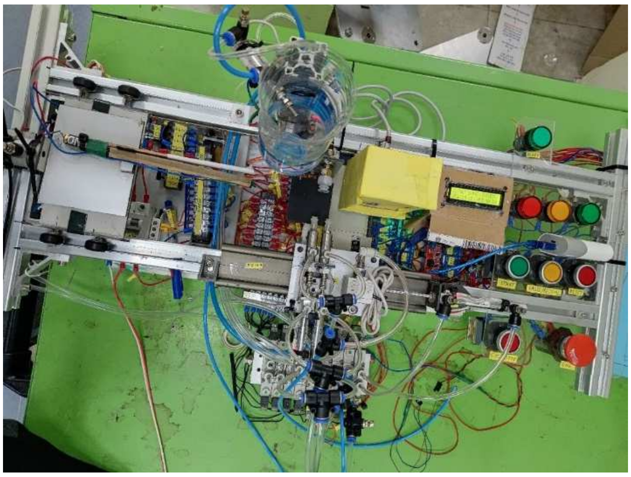

Figure 6 A prototype of machine

The structure satisfies safety requirements and does not vibrate or deform during operation. With the PLC controller, the system operates smoothly in terms of operating modes, indicator signals, and safety requirements.

Figure 7 Load cell and Suction pressure test

The Figure 8 shown the load cell and suction pressure test. The weighing model functions precisely, the error is within the acceptable range, and the signal is sent to the PLC correctly. The Scada monitor screen functions properly, has the ability to issue control commands as if they were genuine external physical keys, the step-by-step monitoring interface is clearly displayed, and each system element's function can be tested an error message is displayed when the period of each step exceeds the set time and the PLC error.

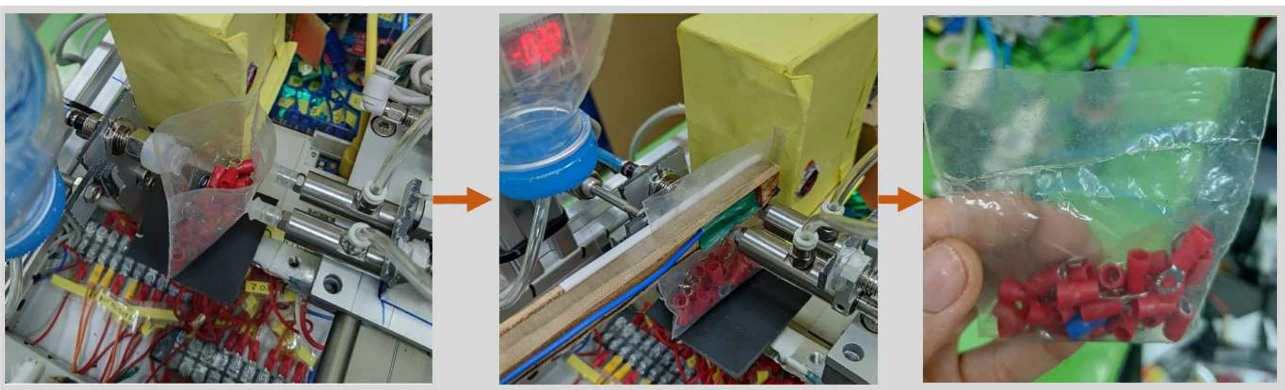

Figure 8 Experimental test

The processing time under normal conditions is approximately 45 seconds. From the stage of opening the bag's mouth with suction pressure to the stage of closing the plastic bag and releasing the completed product as shown in the Figure 8. There is a 50-70 millisecond time delay under standard working conditions. This is an acceptable level based on the design specifications (<100 ms). The pneumatically system worked properly, and the suction pressure is satisfactory for bag opening and closing.

Table 3 Comparison design requirements and experimental results

Parameter	**Requirement**	**Experimental test**
Time cycle	< 60 second	45 second
Time delay	< 100 ms	50-70 ms
Bag size	3x4 cm	3x4 cm
Error weighting	0-1 gram	0.16 gram

The majority of the initial factors, such as bag size, weight, and time, are satisfactory, as shown in Table 3's comparison of initial design requirements and experimental results. Thus, the design prototype satisfies the specifications and can be utilized in actual production. However, the prototype's lack of attractive appearance is a result of its extensive use of readily available materials in an attempt at cost savings.

4 Conclusions

The study presented a prototype for the packaging of plastic bags. The machine was designed and meets the mechanical and electrical requirements. The product is equipped with components such as vacuum, load cell, and a heating part in order to facilitate the packaging process. The prototype functions effectively to ensure that the design requirements are exceeded, and this model is also manufactured at a lower cost than comparable machines. In addition, the proposed prototype can serve as a dependable reference for the future development of improved packaging machines for Vietnam. Future works may involve designing electrical cabinets and product storage systems to enhance the attractive appearance of products. In addition, the vacuum system must be improved so that the machine can be used with bags of various sizes.

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