Revolutionizing Healthcare with 3D/4D Printing and Smart Materials

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***Abstract*— 3D printing technology has revolutionized the way products are manufactured, and it has opened up new possibilities in the field of smart materials. Smart materials are materials that can change their properties in response to external stimuli, such as temperature, pressure, or light. By combining 3D printing technology with smart materials, highly customizable and responsive products are created. The addition of the time dimension to 3D printing has introduced 4D printing technology, which has gained considerable attention in different fields such as medical, art, and engineering. To bridge the gap in knowledge of 4D, this paper assessed the revolution in healthcare with 3D/4D printing and smart materials. Data was generated as part of a broader empirical study which sought to explore healthcare personnel and electrical engineers' perception on the practices around the use of 3D/4D printing technology and smart materials. The main method used was structured interviews. 12 participant were purposively selected and interviewed including healthcare personnel and electrical engineers form Philippines and Nigeria. The findings reveal an array of activities undertaken using both 3D and 4D. Furthermore, the study revealed that 4D printing is a new generation of 3D printing. Another aspect of the 3D usage is the integration of electrical stimulation and smart implant as a new area of study in healthcare. 3D could also be used to monitoring the smart implant performance. The study also evaluate the possibility of using Internet of things (IoT) in the smart implant as some device embeds smart materials. Smart implant commonly used includes orthopedic applications, such as knee and hip replacement, spine fusion, and fracture fixation. The smart materials used in this technology are important because 3D printing allows printed structures to be dynamic. The paper highpoints is that 4D printing has great potential for the future.**

Index Terms—3D printing, 4D printing, healthcare, smart materials, revolutionizing

I. INTRODUCTION

In a wide range of industries, 3D printing technology has a significant impact which many have termed as a game-changer that will continue to be in the coming years. It is also becoming more efficient, accessible, and affordable to as many that desired it. In their early years of development, 3D printing technologies had many limitations in terms of printable materials, achievable geometry, and quality the users had experienced [1]-[3]. However, it was overcome as additive manufacturing technologies matured, they found widespread application in a wide range of industries, including manufacturing, medical, aerospace, automotive, entertainment, and military. Because of the rapid advancement of 3D printing technologies and associated equipment, numerous new opportunities in complex product advanced manufacturing have emerged.

3D printing technology has revolutionized the way products are manufactured, and it has opened up new possibilities in the field of smart materials. Smart materials are materials that can change their properties in response to external stimuli, such as temperature, pressure, or light [4]. By combining 3D printing technology with smart materials, we can create highly customizable and responsive products. One example of the application of 3D printing technology in smart materials is in the development of Shape Memory Alloys (SMAs). SMAs are a class of materials that can "remember" their original shape and return to it when heated above a certain temperature. Using 3D printing, researchers have been able to create complex structures using SMAs, such as actuators and sensors, which can be programmed to respond to specific stimuli. Another example is the use of 3D printing to create smart composites. Smart composites are materials that combine a matrix material, such as a polymer or metal, with embedded smart materials, such as shape memory alloys or shape memory polymers [5]. 3D printing allows for precise control over the placement and orientation of these embedded materials, which can result in highly customizable and responsive composites.

Furthermore, 3D printing can also be used to create smart structures that respond to external stimuli, such as temperature or humidity. These structures can be designed to change their shape or properties in response to specific conditions. For example, a 3D-printed smart structure could be designed to open or close in response to changes in temperature or humidity. 3D printing technology has enabled the development of highly customizable and responsive products using smart materials. The combination of these two technologies has opened up new possibilities in various fields, such as healthcare, aerospace, and robotics.

A. The use of 3D printing using smart material in healthcare

3D printing technology has been applied in various ways in the healthcare field, and the use of smart materials in 3D

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printing has led to innovative solutions to various healthcare challenges. Here are a few examples:

- 3D-Printed Medical Implants With Shape Memory Alloys: 3D printing technology has enabled the production of customized medical implants using smart materials like shape memory alloys [6]. For example, a 3D-printed stent made of a shape memory alloy can be designed to change shape in response to body temperature, allowing for better integration with surrounding tissues and reducing the risk of complications.
- 3D-printed smart drug delivery systems: Smart materials like hydrogels, which can change their volume or shape in response to specific stimuli like temperature or pH, have been used in 3D-printed drug delivery systems [7],[8]. These systems can release drugs in a controlled manner and can be programmed to respond to specific signals within the body.
- 3D-Printed Sensors for Prosthetics: Smart materials like conductive polymers can be used in 3D-printed sensors to improve the functionality of prosthetics [9]-[11]. These sensors can detect pressure and temperature changes, providing feedback to the user and improving the accuracy and precision of prosthetic movements.
- 3D-Printed Models for Surgical Planning: 3D printing technology has also been used to create highly detailed anatomical models that can aid in surgical planning and education. These models can be 3D-printed using smart materials like bioresorbable polymers that can be safely absorbed by the body over time [12],[13].

Overall, the use of 3D printing with smart materials has led to innovative solutions in healthcare, providing customized and responsive solutions for patients with a wide range of medical needs.

B. Ethical Issues on the Use of 3D Printing Product in Healthcare

The use of 3D printing in healthcare raises several ethical issues that need to be addressed. The ethical issues as enumerated by Ref. [14]-[16] include among others:

- Quality and safety concerns: 3D printing of medical devices and implants, especially those using smart materials, may raise questions about their quality and safety. Regulators and healthcare providers need to ensure that 3D printed devices are produced using appropriate quality control measures and meet safety standards.
- Intellectual property and patent infringement: 3D printing of medical devices can infringe on existing patents or proprietary designs, and this can raise ethical questions. Manufacturers, researchers, and healthcare providers need to ensure that they respect existing patents and intellectual property rights.
- Privacy and data protection: 3D printing of personalized medical devices requires access to patient data, and this raises concerns about privacy and data protection. Healthcare providers need to ensure that they collect and process patient data in accordance with applicable privacy laws.
- Access and affordability: 3D printing of medical devices may increase access to healthcare for patients who live in remote or underserved areas, but it may also raise concerns about affordability. Healthcare providers and regulators need to ensure that 3D printing technology does not widen the existing healthcare gap between the rich and the poor.
- Ethical considerations for 3D printing of human tissues and organs: 3D printing of human tissues and organs, such as 3D printed organs for transplant, raises significant ethical considerations. The use of 3D printing technology in this area needs to be guided by ethical principles such as transparency, safety, and informed consent.

Here is a brief explanation of each 3D printing technology:

- Fused Deposition Modeling (FDM): FDM is a common 3D printing technology that works by heating and extruding a thermoplastic material, such as ABS or PLA, through a small nozzle [17],[18]. The printer deposits the molten material layer by layer, building up the object from the bottom up. FDM is often used for creating low-cost, large-scale objects with simple shapes.
- Stereolithography (SLA): SLA is a type of 3D printing that uses a laser to cure a liquid photopolymer resin into a solid object. The printer uses a laser to draw the desired shape of the object on the surface of the resin, causing the resin to solidify where the laser hits it [17],[19]. The printer then lowers the object into the resin tank and repeats the process layer by layer until the object is complete. SLA is often used for creating high-resolution objects with intricate geometries.
- Selective Laser Sintering (SLS): SLS is another 3D printing technology that uses a laser to fuse a powdered material, such as nylon, into a solid object. The printer spreads a thin layer of the powdered material on a build platform and then uses a laser to selectively melt and fuse the particles together according to the desired shape of the object [20],[21]. The printer then adds another layer of powder and repeats the process layer by layer until the object is complete. SLS is often used for creating objects with complex geometries and high strength.
- Inkjet-based 3D printing: Inkjet-based 3D printing is a relatively new type of 3D printing that works by depositing droplets of material onto a build platform. The printer uses a series of printheads to deposit the material in layers, similar to how an inkjet printer deposits ink onto paper [22]-[24]. The printer can use a wide range of materials, including polymers, metals, ceramics, and even biological materials. Inkjet-based 3D printing is often used for creating objects with complex geometries and high resolution.

The choice of 3D printing technology will depend on the specific requirements of the 4D-printed object, such as the size, shape, and properties of the object, as well as the type of smart material used. Each technology has its own advantages and limitations, and the best choice will depend on the specific application.

In summary, the use of 3D printing technology in healthcare raises important ethical considerations, and healthcare providers, regulators, and researchers need to address these issues to ensure that 3D printing technology is used ethically and responsibly in healthcare.

C. 4D Printing Technology in Healthcare

3D printing is a cutting-edge technology with some flaws, this manufacturing process offers numerous advantages. In comparison to traditional manufacturing methods such as computer numerical control (CNC), milling, and turning, additive manufacturing provides advantages such as more flexibility and shorter manufacturing cycle times [25]. Despite its limitations, 3D printing technology has enormous benefits. To overcome the limitations of 3D printing, a new technology known as 4D printing was developed.

According to Ref. [26], [27], 4D printing refers to Additive Manufacturing (AM) of objects that can self-transform in form or function when exposed to a predetermined stimulus such as osmotic pressure, heat, current, ultraviolet light, or other energy sources. The manufacturing of objects in 3D printing is based on the three geometrical axes x, y, and z, but in 4D printing, there is a new dimension, the "time" dimension. This does not include the time it took to complete the printing. Instead, it represents the passage of time as objects undergo shape transformation and is cited as the primary distinction between 3D and 4D printing. In other words, 4D printing means "3D printing and time," according to Momeni, Liu, and Ni (2017). To begin the transformation of 4D printing, one specific stimulus is required. This can include humidity, heat, light, electrical fields, and other factors. To respond to these stimuli, unique materials are used in this case. These materials have programmable properties that can form when the stimuli are applied. According to Ref. [28], one of the critical advantages of 4D printing technology over 3D printing is the ability to build dynamic structures using smart materials. Because living tissues or organs have a dynamic structure, this technology has great potential for printing them [25].

Because of the advantages of 4D printing, Ref. [29] maintained that it has more applications than 3D printing. As smart materials are used in 4D printing, the objects can have the following characteristics: self-assembly, self-disassembly, self-sensing, self-folding, self-repairing, and self-adaptability [30]. For example, using stimuli-responsive materials, this innovative technology can create a bone that has the ability to expand in the human body over time [25]. As a result of the use of smart materials and the fabrication of flexible parts, 4D printing novel technology meets a variety of standards.

D. Opportunities Available in 4D Printing Technology for Healthcare Scientists

The mechanism behind the change in shape or properties over time in response to external stimuli in 4D printing involves the use of "smart" materials, which are designed to respond to specific stimuli in a predictable and controlled manner. There are several types of smart materials that can be used in 4D printing, including shape-memory polymers [31], hydrogels [32], and liquid crystal elastomers [33],[34]. Shape-memory polymers are a common type of smart material used in 4D printing. These materials are designed to "remember" their original shape, which can be programmed into the material through a process called "shape fixing". When exposed to a specific stimulus, such as heat or light, the shape-memory polymer will "recover" its original shape, which can result in a change in the overall shape or properties of the printed object [31].

According to Ref. [32], hydrogels are another type of smart material used in 4D printing. These materials are made of networks of cross-linked polymer chains that can absorb large amounts of water, making them ideal for use in medical applications. When exposed to specific stimuli, such as changes in temperature or pH, the hydrogel can swell or shrink, which can result in a change in the overall shape or properties of the printed object. Liquid crystal elastomers are a type of smart material that can change their shape and properties in response to changes in temperature or light. These materials consist of polymer chains that are aligned in a specific direction, which gives them unique mechanical properties. When exposed to specific stimuli, the liquid crystal elastomer can change its alignment and shape, which can result in a change in the overall shape or properties of the printed object [34]. The mechanism behind the change in shape or properties over time in response to external stimuli in 4D printing involves the use of smart materials that are designed to respond to specific stimuli in a predictable and controlled manner. By programming the smart materials to respond to specific stimuli, researchers can create dynamic and adaptable three-dimensional structures that have a wide range of potential applications in healthcare, engineering, and other fields.

4D printing technology offers significant opportunities in healthcare sciences. Here are some examples of how 4D printing can be used in healthcare:

- Smart implants: 4D printing can be used to create smart implants that can change shape or properties in response to specific stimuli, such as temperature or pH. This can help to improve the biocompatibility of the implant and reduce the risk of rejection or infection.
- Tissue engineering: 4D printing can be used to create structures that mimic the complex three-dimensional architecture of tissues and organs, which can be used for tissue engineering or regenerative medicine. By using smart materials that can change shape or properties over time, researchers can create structures that can grow and adapt to their environment.
- Drug delivery systems: 4D printing can be used to create drug delivery systems that can release drugs in a controlled manner over time. By using smart materials that can respond to specific stimuli, such as temperature or pH, researchers can create drug delivery systems that are triggered to release drugs at specific times or locations in the body.
- Surgical tools: 4D printing can be used to create surgical tools and devices that can change shape or properties during surgery, which can help to improve surgical outcomes and reduce the risk of complications.

In the last decade, 4D printing technology has advanced dramatically. Since its inception, and has expanded its influence in various industrialized areas. 4D printing frequently employs additive manufacturing techniques with stimuli-responsive materials to induce a shape-changing mechanism with time. It provides excellent flexibility and adaptability because a single printed object can potentially serve multiple operations [35]. To put it another way, 4D printing is the next generation of 3D printing. Stimuli-responsive materials used in this technology are extremely

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important as smart materials, and 3D printing technology enables dynamic printed structures.

This characteristic demonstrates that 4D printing has a bright future. It has been used successfully in fields requiring dynamic constructions, such as tissue engineering and organ transplants. Ref. [36],[37] suggested that 4D printing can be developed by combining imaging techniques such as CT scans and MRI to create customized implants, specific prosthetics, and anatomic models. Despite numerous advancements, 4D printing is still in its early stages. As a result, more research on 4D printing technology parameters, such as stimulus-responsive materials, imaging methods, additive manufacturing approaches, and stimulus, is required. The material limits the progress of 4D printing. Although the materials used for 4D printing should be sensitive, not all materials are stimulus-responsive, and not all stimulus-responsive materials can be used for printing devices [38]. Furthermore, the majority of the materials only react to a single stimulus. Exploring new responsive materials and making existing responsive materials printable is thus a future path for this technology.

E. 4D Printer Used in Healthcare

There are several examples of 4D printers currently available on the market or in development by research institutions. Here are a few examples:

- Stratasys J750 Digital Anatomy Printer: This printer uses PolyJet technology to print anatomical models with a range of textures and properties that simulate human tissue [39]. The printer can also be used to print models that change shape or properties over time in response to specific stimuli.
- MIT Self-Assembly Lab's Rapid Liquid Printing: This printing technology uses a robotic arm to deposit liquid materials in a 3D space, allowing for the creation of large-scale objects with dynamic properties [40]. The printed objects can change shape or properties over time in response to specific stimuli.
- HP Jet Fusion 5200 Series 3D Printer: This printer uses Multi Jet Fusion technology to print objects with a range of properties, including color, texture, and conductivity [41],[42]. The printer can also be used to print objects that change shape or properties over time in response to specific stimuli.
- University of Illinois at Urbana-Champaign's 4D Lab: This research group has developed several 4D printers that can print objects with a range of dynamic properties, including shape-memory polymers, hydrogels, and liquid crystal elastomers [43]. The printers can be used to create a wide range of innovative tools and devices, including medical implants and soft robotics.

Overall, 4D printing technology is a rapidly advancing field, and there are many innovative printers being developed and used by researchers and companies around the world. The main technology used in 4D printing is additive manufacturing, which is the process of creating 3D objects by layering materials on top of each other. However, 4D printing goes beyond traditional 3D printing by using "smart materials" that can change shape or properties over time in response to specific stimuli, such as temperature, moisture, or light. These smart materials are typically designed to respond to environmental changes by undergoing a structural transformation, such as a change in shape, size, or stiffness. This transformation can be triggered by a variety of external stimuli, such as changes in temperature, pH, or electromagnetic fields. To create 4D printed objects, the smart material is first programmed with a specific shape or function, and then printed using traditional 3D printing techniques. Once the object is printed, it can be triggered to transform into its desired shape or function in response to a specific environmental stimulus.

The printing technique used in 4D printing technology is generally similar to traditional 3D printing techniques. The primary difference is that 4D printing involves the use of "smart materials" that can change shape or properties over time in response to specific stimuli, which are integrated into the printed object during the printing process. There are several different types of 3D printing technologies that can be used for 4D printing, such as Fused Deposition Modeling (FDM), Stereolithography (SLA), Selective Laser Sintering (SLS), and Inkjet-based 3D printing. The choice of printing technology will depend on the specific requirements of the 4D-printed object, such as the size, shape, and properties of the object, as well as the type of smart material used. In addition to the printing technology, the 4D printing process also involves the design and programming of the smart material to achieve the desired shape or function when triggered by a specific stimulus. This programming can be done using a variety of techniques, such as computer-aided design (CAD) software, simulation tools, or machine learning algorithms.

F. The differences between 3D and 4D printing

3D printing and 4D printing are similar in that they both involve the use of additive manufacturing to create three-dimensional objects. However, there are some key differences between the two technologies. 3D printing, as its name implies, refers to the creation of a three-dimensional object by layering materials on top of each other. The materials used in 3D printing are typically rigid and do not change shape after the printing process is complete. Traditional 3D printing relies on using different types of materials to create different parts of an object [44],[45].

4D printing, on the other hand, involves the use of "smart" materials that can change shape or properties over time in response to specific stimuli, such as temperature, light, or humidity. These materials are designed to respond to external stimuli in a predictable and controlled manner, allowing for the creation of dynamic structures that can move, fold, or unfold. In essence, 4D printing adds an element of time to the printing process, allowing the printed object to transform into a new shape or form over time [46].

To summarize, 3D printing creates static three-dimensional objects by layering materials on top of each other, while 4D printing involves the use of smart materials that can change shape or properties over time in response to external stimuli, resulting in dynamic and adaptable three-dimensional structures.

II. Objective of the Study and Research Questions

The main purpose of the study was to assess the revolution in healthcare with 3D and 4D Printing and Smart Materials. Specifically, the study sought to determine the:

- The current state of 4D printing technology in healthcare
- The commonly use smart implant?

- The electronic types used in smart printing

The research Questions are:

- What is the current state of 4D printing technology in healthcare?
- What are the commonly used smart implants?
- What is the electronic types used in smart printing?

III. Methods

The study which was qualitative in nature adopted cross-sectional research design and was conducted in two countries (Philippines and Nigeria). The study employed a purposive sampling technique to select the respondent from two separate fields, i.e. medical practitioners and electrical engineers. However, the study's data was obtained from both primary and secondary sources. According to Ref. [47] primary and secondary data can be used in a study in as much as the data are relevant and useful. The main methods were partially structured recorded qualitative interviews – gently guided discussions with a conversational partner (Healthcare Personnel and electrical engineers interactions). Thematic data analysis was used to identify themes which "represent some level of patterned response or meaning within the data set" [48]. The secondary data were obtained from literatures and was analyzed to answer the research questions.

IV. Results and Discussion

A. Research Questions 1: What is the current state of 4D printing technology in healthcare?

1) Theme 1: The pioneers of 3D printing technology

In an interview with a printing expert in Nigeria, the expert lay bare the pioneers of 3D printing. In is words:

"... You see the issue of 3D printing, the United States of America hold the credit for been the first country in the world to have started using and developing it. Though after USA have started, other countries like United Kingdom, China and Germany also keyed into it development. These countries also brought in new innovation to the use of 3D printing especially in pharmaceuticals".

An interview with a printing engineer in Philippines shows that there was no different perception as to who were the pioneers of the 3D printing technology as the engineer has this to say.

"*... 3D printing technology was first developed in the United States in the 1980s. While the US is often credited as the pioneer of 3D printing technology, the technology has been adopted and advanced by many other countries around the world. Today, there are 3D printing companies, research institutions, and startups operating in many countries, including China, Japan, Germany, the UK, and many others".*

This also confirms the report by Ref. [49]-[51] who in their submissions reiterated that though 3D printing started in the 1980s by the Americans, it has created a new milestone in the development of pharmaceuticals. Ref. [52] asserted that the human health system requires the best medical attention and remedies which the 3D is providing. As the body system need proper care, appropriate steps has to be taken to ensure that what is embedded or implanted as little or no side effect on the total well-being of the patient.

In terms of healthcare applications, many countries are actively using 3D printing to create anatomical models for surgical planning and other medical purposes. A healthcare personnel said

"*… 3D technology is also being used to create customized medical implants and prosthetics, and to develop new drugs and medical devices".*

Ref. [53]-[55] all opined that on the overall, the development and adoption of 3D printing technology is a global effort that involves many countries and organizations in order to remedy the high rate of human loss of life and other anatomy of the human body.

2) Theme 2: The current state of the art on the use 4D printing technology in healthcare

The innovation to the 3D printing technology had given birth to what is now termed as 4D printing technology. In an effort to by the researchers to discover the current state of the use of 4D printing technology, a printing engineer from Philippines was interviewed and in the course of the interview made mention that

"... the use of 4D printing technology in healthcare is still in its early stages, but there has been significant progress in recent years, and the potential applications are vast. Some of the current state-of-the-art applications of 4D printing in healthcare include: Self-assembling surgical tools, Smart implants, Drug delivery systems, Soft robotics".

To support the above finding, Ref. [56]-[59] affirmed that there is still much work to be done to fully realize the potential of 4D printing in healthcare, the technology has already shown significant promise and is expected to play an increasingly important role in the future of healthcare. As at present, Some of the current state-of-the-art applications of 4D printing in healthcare include: Self-assembling surgical tools, Smart implants, Drug delivery systems, Soft robotics.

3) Theme 3: 4D printing technology as an advancement of 3D printing technology

When asked whether 4D is an advancement of 3D printing technology, engineers from both Nigeria and Philippines responded:

"... Yes, we can say that 4D printing technology is an advancement of 3D printing technology. 4D printing builds on the capabilities of 3D printing by introducing smart materials that can change shape or properties over time in response to external stimuli, resulting in dynamic and adaptable three-dimensional structures. In other words, 4D printing adds a time element to 3D printing, allowing objects to transform and adapt to changing conditions".

In like manner, engineers from Nigeria where of the same opinion. They asserted that:

"...While 3D printing has revolutionized the manufacturing industry, 4D printing has the potential to expand the applications of 3D printing even further, particularly in fields such as healthcare, robotics, and construction. By enabling objects to change shape and function in response to their environment, 4D printing could lead to the development of more efficient, adaptable, and responsive products".

In line with the above findings, Ref. [60] opined that the use of 4D printing technology in healthcare emanates from the initial technology called 3D. The shortcomings experienced in the use of 3D printing technology necessitated the engineers to come up with a more efficient and effective technology named 4D printing. However, According to Ref.

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[60], it is important to note that 4D printing is still a relatively new technology, and many technical and practical challenges need to be addressed before it can become widely adopted. Nevertheless, the progress made in 4D printing so far is promising, and it's likely that we will see continued advancements and applications of the technology in the coming years.

4) Theme 4: Is there any correlation between electrical stimulation and smart implant in 4D printing technology?

In understanding the correlation between electrical stimulation and smart implant in 4D printing technology electrical engineers were interviewed across the two countries (Nigeria and Philippines). However, the engineers from both countries have almost the same ideology and perception about electrical stimulation and smart implant in 4D printing technology.

"…There is potential for correlation between electrical stimulation and smart implants in 4D printing technology, as both technologies involve the use of sensors to provide real-time data on physiological responses. Electrical stimulation can be used to activate or inhibit neural pathways, while smart implants can measure physical parameters from inside the body and transmit this data to external devices for monitoring and analysis."

Ref. [61] maintained that the integration of electrical stimulation with smart implant technology could allow for more precise and targeted therapies, as well as improved monitoring of patient responses to treatment. However, Ref. [62] noted that this area of research is still in its early stages and further investigation is needed to fully explore the potential benefits and limitations of this approach (Electrical Engineer from Philippines)".

In providing more details on the correlation between electrical stimulation and smart implant in 4D printing technology, an interview with both healthcare personnel and printing/electrical engineers revealed that:

"… Certainly! While electrical stimulation and smart implants are not directly related to 4D printing technology, they are both areas of active research and development in the field of healthcare technology (Healthcare Personnel from Philippines)."
"… Electrical stimulation, in particular, has been studied extensively for its potential therapeutic benefits in various medical applications, including wound healing, tissue regeneration, and pain management. The basic principle of electrical stimulation is to apply controlled electrical currents to targeted areas of the body, which can promote cellular activity and tissue repair (Electrical Engineer from Philippines)".
"… Smart implants is an implantable device that has both therapeutic and diagnostic capabilities. These devices can provide real-time feedback on a patient's condition, such as temperature, pressure, or force, and can also be programmed to respond to specific stimuli in order to deliver a therapeutic response (Electrical Engineer from Nigeria)".

This revelation is in line with Ref. [25] who maintained that electrical stimulation and smart implant are to different concepts which can both ne used in the medical field. Ref. [25] further reiterated that the major aim of electrical stimulation in 4D printing technology is to control the current (electrical) that flows to a targeted areas in the human body. Furthermore, Ref. [26] submitted that smart implants is majorly concern with the therapeutic and diagnostic of the human body. Mentioning Ref. [26] noted that the basic importance of the 4D printing technology is the provision of real-time feedback on a patient's condition. It provides information and remedies to some specific stimuli in an effort to dose of either pains or abnormality.

B. Research Questions 2: What are the commonly used smart implants?

1) Theme 1: Smart implant commonly used

Currently, smart implants are not yet widely and extensively used in clinical practice, but there is ongoing research and development in this field. The interviewee noted that:

"… The few smart implants that have been used in clinical studies or approved for use are mostly used in orthopedic applications, such as knee and hip replacement, spine fusion, and fracture fixation (Electrical Engineer)"

Ref. [60],[63] recounted that smart implant used are designed to provide not only therapeutic benefits but also diagnostic capabilities, allowing for the measurement of physical parameters from inside the body, such as pressure, force, strain, displacement, proximity, and temperature. The data from these smart implants can be used to refine implant design, surgical technique, and postoperative care and rehabilitation strategies.

Data from literature available shows that

"… Smart implants are implantable devices that provide not only therapeutic benefits but also have diagnostic capabilities. The integration of smart implants into daily clinical practice has the potential for massive cost savings to the health care system. Applications for smart orthopedic implants have been identified for knee arthroplasty, hip arthroplasty, spine fusion, fracture fixation and others. To date, smart orthopedic implants have been used to measure physical parameters from inside the body, including pressure, force, strain, displacement, proximity and temperature". "The measurement of physical stimuli is achieved through integration of application-specific technology with the implant. Sensors for next-generation smart implants will be small, simple, robust and inexpensive and will necessitate little to no modification to existing implant designs. With rapidly advancing technology, the widespread implementation of smart implants is near. New sensor technology that minimizes modifications to existing implants is the key to enabling smart implants into daily clinical practice". [57],[58]

From Philippines, a healthcare personnel said

"*…The use of smart implants in healthcare has indeed shown promising potential for improving patient outcomes and reducing healthcare costs".*

The researchers in this article suggests, there are still significant technical challenges that need to be overcome before smart implants become part of mainstream healthcare.

2) Theme 2: The integration of electrical stimulation and smart implant as a new area of study in healthcare

The integration of electrical stimulation and smart implants is already an area of study in healthcare, and it is expected to continue to be an important area of research in the future. Electrical stimulation is a well-established technique for stimulating tissue growth and regeneration, and it has been used in a variety of medical applications, including bone and tissue regeneration, wound healing, and pain management.

In an interview with a healthcare personnel, the interviewee expressed that:

"... Smart implants have the potential to provide valuable information about the condition of the implant and the surrounding tissue. By integrating electrical stimulation with smart implants, it may be possible to monitor the response of the tissue to electrical stimulation and adjust the stimulation parameters in real-time to optimize the therapeutic effect".

Another interviewee a health personnel said:

"... The use of smart implants that are capable of providing electrical stimulation may also have the potential to improve the healing of tissue around the implant. For example, the implant could be designed to provide electrical stimulation to the surrounding tissue to promote blood flow and prevent the buildup of scar tissue."

Ref. [64],[65] asserted that the integration of electrical stimulation and smart implants is an exciting area of research in healthcare, and it has the potential to lead to significant advancements in the field of regenerative medicine. However, the use of smart implant is to help hasten the healing process and also form part of the body function organs.

C. Research Questions 3: What is the Electronic types used in smart printing?

1) Theme 1: device that embeds smart implant

The respondents indicated that the specific devices embedded in smart implants can vary depending on the application and purpose of the implant. However, the common components found in smart implants include:

... sensors, microprocessors, wireless communication modules, and power sources such as batteries or energy-harvesting systems.

In conformity with the findings of Ref. [64],[65] indicated that sensors are typically used to monitor various parameters such as pressure, force, temperature, and strain, while the microprocessors process the collected data and perform specific functions based on the programmed logic. The wireless communication modules enable real-time data transmission to external devices, such as smartphones or computers, for analysis and monitoring [66].

2) Theme 2: Possibility of using Internet of things (IoT) in the smart implant

It is technically possible to use IoT (Internet of Things) in a smart implant, but the size of the device would likely be a limiting factor. IoT typically involves connecting a device to the internet to allow it to send and receive data, which requires the device to have a wireless connection and a certain amount of processing power to handle data communication. While it may be feasible to embed an IoT device in a smart implant, it would need to be small enough to fit within the implant and have very low power consumption to ensure long battery life.

In an interview with healthcare personnel, the interviewee expresses concerned over the safety of the patient who will bear the implant. The health personnel said:

"... Using IoT in a smart implant is possible, but, there may be concerns about the safety and security of the implant if it is connected to the internet, which would need to be addressed in any design."

"... What I can say is that, while it is theoretically possible to use IoT in a smart implant, it may not be a practical or widely used solution at present."

The specific type of electronic components used in a smart implant can vary depending on the intended function and application of the implant. In general, the electronic components used in smart implants need to be small, lightweight, and low-power in order to fit within the implant and avoid causing tissue damage or interfering with the body's normal function.

3) Theme 3: Monitoring the smart implant performance

Smart implants are monitored using a variety of techniques, depending on the specific application and the type of sensor or device embedded in the implant.

"... data from the smart implant is wirelessly transmitted to an external device, such as a smartphone or computer, where it can be analyzed by the healthcare provider. This allows for real-time monitoring of the implant's performance and early detection of potential issues."

In accordance with the findings, Ref. [67] opined that the smart implant may also have an onboard power source and data storage, which allows for more detailed analysis of the data over longer periods of time. Furthermore, according to Ref. [68], a smart implant for joint replacement may record data on the patient's movement patterns and transmit this data to the healthcare provider for analysis over the course of several months or years.

Ref. [64] maintained that smart implants can provide continuous monitoring of critical intracorporal parameters, a low-cost, as well as a high-performance technology for preclinical research. In the same vein, Ref. [68],[69] noted that by using ultra-wideband communication, the status of a patient is monitored and the results obtained will widely be used for bettertreatment and management of heath conditions.

Overall, the goal of monitoring the performance of smart implants is to optimize their effectiveness and ensure that they are functioning as intended. This can lead to better patient outcomes and improved quality of life for those who rely on these implants for their daily activities.

V. CONCLUSION

3D printing technology has developed significantly over the past decade. Since its inception, its influence has spread to various industrialized fields, especially the field of health. 3D and 4D printing often uses additive manufacturing techniques and smart materials to create shape mechanisms that change over time. This provides greater flexibility and customization, as a print object can potentially be used for important operations. The study concluded that 4D printing is a new generation of 3D printing. Another aspect of the 3D usage is the integration of electrical stimulation and smart implant as a new area of study in healthcare. 3D could also be used to monitoring the smart implant performance. The study also evaluate the possibility of using Internet of things (IoT) in the smart implant as some device embeds smart implant. Smart implant commonly used includes orthopedic applications, such as knee and hip replacement, spine fusion, and fracture fixation. The smart materials used in this technology are important because 3D printing allows printed structures to be dynamic. This feature shows that 4D printing has great potential for the future. Therefore, further research is needed

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on the technical parameters of 4D printing, including stimuli-responsive materials, imaging methods, additive manufacturing methods, and stimuli. Smart materials for 3D and 4D printing must be responsive; however, not all smart materials are stimuli-responsive, and not all stimuli-responsive materials can be used in printed devices. Also, most materials only respond to single stimuli. Despite the challenges, the future of 4D printing technology remains bright.

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