Advanced Materials Empowering Inclusive Engineering Design Processes

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Abstract. The purpose of this research is to identify advanced and smart material solutions suitable for the design of environments, systems, experiences and products according to design for all criteria, an inclusive methodology whose principles state that products and services should be respectful of diversity, safe, functional, healthy, understandable and aesthetic. While designed smart materials have the ability to respond to external stimuli and reversibly and repeatedly change their properties and functions, thus adapting to a wide variety of environments and purposes, a significant number of common manufacturing technologies and materials has proven to be insufficiently performing or feature inadequate sets of physical and technical properties for the engineering of tailored objects, surfaces and devices aiming to match human diversity. This study suggests that state-of-the-art material solutions, among which are nanomanufacturing and advanced AM technologies, represent cutting-edge design tools for the devising and engineering of human diversity-tailored intelligent systems and environments.

Keywords: Accessibility · Advanced AM · Enabling technologies
Inclusive engineering design processes · Large scale nanomanufacturing
Programmable smart materials · Sensory and mobility challenged user
Visual impairment

1 Introduction

The purpose of this research is to identify advanced and smart material solutions suitable for the design of environments, systems, experiences and products according to design for all criteria, an inclusive methodology whose principles, according to the Design for All Foundation, state that "products and services should be respectful of diversity, safe, functional, healthy, understandable and aesthetic"[1] [1]. While designed smart materials

[1] The Design for All Foundation has defined seven Design for All criteria - Respectful, Safe, Healthy, Functional, Comprehensible (Clear information, Spatial distribution), Sustainable, Affordable and Appealing - as well as seven product or service development strategies: "To Everyone", "Adjustable", "Products or services range", "Compatible with commonly used accessories", "Premises/Product & complementary service", "Use an alternative solution to the mainly used offering similar benefits" and "Customized product or service".

W. Karwowski and T. Ahram (eds.), *Intelligent Human Systems Integration*,
Advances in Intelligent Systems and Computing 722,
https://doi.org/10.1007/978-3-319-73888-8_117

have the ability to respond to external stimuli and reversibly and repeatedly change their properties and functions, thus adapting to a wide variety of environments and purposes, a significant number of common manufacturing technologies and materials has proven to be insufficiently performing or feature inadequate sets of physical and technical properties for the engineering of tailored objects, surfaces and devices aiming to match human diversity (Fig. 1).

Sex/age group	Percent							
	World	High-income countries	Low-income and middle-income countries, WHO region					
			African	Americas	South-East Asia	European	Eastern Mediterranean	Western Pacific
Severe disability								
Males								
0–14 years	0.7	0.4	1.2	0.7	0.7	0.9	0.9	0.5
15–59 years	2.6	2.2	3.3	2.6	2.7	2.8	2.9	2.4
≥ 60 years	9.8	7.9	15.7	9.2	11.9	7.3	11.8	9.8
Females								
0–14 years	0.7	0.4	1.2	0.6	0.7	0.8	0.8	0.5
15–59 years	2.8	2.5	3.3	2.6	3.1	2.7	3.0	2.4
≥ 60 years	10.5	9.0	17.9	9.2	13.2	7.2	13.0	10.3
All people								
0–14 years	0.7	0.4	1.2	0.6	0.7	0.8	0.9	0.5
15–59 years	2.7	2.3	3.3	2.6	2.9	2.7	3.0	2.4
≥ 60 years	10.2	8.5	16.9	9.2	12.6	7.2	12.4	10.0
≥ 15 years	3.8	3.8	4.5	3.4	4.0	3.6	3.9	3.4
All ages	2.9	3.2	3.1	2.6	2.9	3.0	2.8	2.7

Sex/age group	Percent							
	World	High-income countries	Low-income and middle-income countries, WHO region					
			African	Americas	South-East Asia	European	Eastern Mediterranean	Western Pacific
Moderate and severe disability								
Males								
0–14 years	5.2	2.9	6.4	4.6	5.3	4.4	5.3	5.4
15–59 years	14.2	12.3	16.4	14.3	14.8	14.9	13.7	14.0
≥ 60 years	45.9	36.1	52.1	45.1	57.5	41.9	53.1	46.4
Females								
0–14 years	5.0	2.8	6.5	4.3	5.2	4.0	5.2	5.2
15–59 years	15.7	12.6	21.6	14.9	18.0	13.7	17.3	13.3
≥ 60 years	46.3	37.4	54.3	43.6	60.1	41.1	54.4	47.0
All people								
0–14 years	5.1	2.8	6.4	4.5	5.2	4.2	5.2	5.3
15–59 years	14.9	12.4	19.1	14.6	16.3	14.3	15.5	13.7
≥ 60 years	46.1	36.8	53.3	44.3	58.8	41.4	53.7	46.7
≥ 15 years	19.4	18.3	22.0	18.3	21.1	19.5	19.1	18.1
All ages	15.3	15.4	15.3	14.1	16.0	16.4	14.0	15.0

Fig. 1. The table shows the estimated prevalence of moderate and severe disability, by region, sex, and age, Global Burden of Disease estimates for 2004 [2].

Studies like the *World report on ageing and health* conducted by the World Health Organization in 2015 clarify that the lack of infrastructure and resources that might enable persons with restricted capacities to perform necessary or desired activities may significantly decrease life expectancy [3], thus implicitly pointing out the importance of inclusive, enabling environments.

2 Forefront Material Functionalities and Performances for Inclusive Innovations

The latest developments in the field of innovative and smart materials feature a relevant application potential in relation to inclusive design. Advanced functionalities imparted to materials, such as multi-responsive shape memory [4], multiple transition capabilities [5], innovative glide properties [6], thermo-intelligence [7], as well as high precision material design options, as are those offered by materials such as engineering magnets [8], programmable textile products [9], triggerless shape-shifting blends [10] and customizable specialty alloy [11] formulations, serve the inclusive engineering design process by concretely improving accessibility and usability of the final products and systems for both everyday and specific use. Contexts of use include, but are not limited to, work and study environments, domestic and public spaces, education and training opportunities or access to art and culture, travel and leisure.

Permanent and temporary disability are complex multidimensional experiences often requiring materials available in multiple or otherwise easily adaptable formats, in order to grant full accessibility to both the domestic and public sphere.

The adoption of advanced AM (additive manufacturing) technologies enables the customization and modification of components as well as the manufacture of functional parts featuring complex morphologies using smart materials specifically developed for 3D printing purposes: perfected filaments and powders feature intrinsic predesigned properties, including self-lubricating [12], shape-shifting [13] and self-reinforcing [14]. Novel body temperature-triggered, shape-changing polymers [15] require lower temperatures than the previous generations, enabling them to be responsive to mere body heat, and possess the ability to store large amounts of elastic energy, allowing them to perform remarkable mechanical work during the shape recovery phase. These innovative SMPs (shape-memory polymers) are light and easily formable materials suitable, among other, for numerous applications in the biomedical field (Fig. 2).

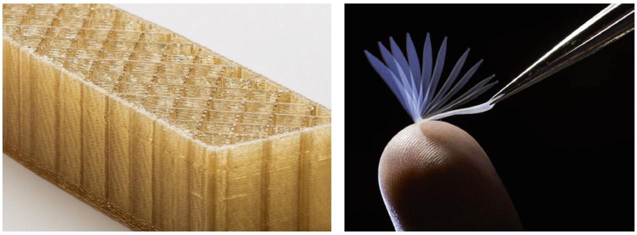

Fig. 2. a. Complex part printed with self-reinforcing filaments [16]. b. A body temperature-triggered poly (caprolactone) SMP reverting back to its initial shape (time-lapse photograph) [15].

AM technologies may also enable people with visual disabilities quality access to works of art, as proven by Didú [17], the multidisciplinary methodology for the conversion of digital images into high haptic quality relief images developed by the company Estudios Durero, through which photographs and pictorial images are virtually translated into their three-dimensional counterpart to be touched and felt by the blind and visually impaired, as well as the seeing.

3 Technologies Enhancing Cognitively Ergonomic System and Device Engineering

Furthermore, the findings show that latest nanomanufacturing solutions [18] include patented manufacturing processes, which enable materials and components to be produced for large products and devices in high volumes. Enhanced production possibilities determine an augmented application potential matching, even very demanding project requirements, while increased material sensitivity produces improved responsivity from surfaces, e.g. making touch gestures, identified as a frequent cause for user discrimination, easier and more effective [19].

NanoWeb® [20] is a flexible transparent conductor made of a nanostructured thin metal layer consisting of a two-dimensional mesh of continuous wires able to remain invisible to the human eye, due to its high conductivity and consequent low operating power. It may be fabricated onto any plastic or glass substrate and represents a high-performance alternative to Indium Tin Oxide (ITO) products, as well as ITO-alternative technologies, such as silver nanowire (AgNW), graphene and carbon nanotubes (CNT) suitable for both small, or large surfaces areas. It has been developed by the company Metamaterial Technologies Inc. (MTI) using the patented manufacturing process Rolling Mask Lithography® (RML) [21], which enables NanoWeb® to be produced for large products and devices, as well as films in roll-to-roll production. Its low production cost makes it suitable for large scale manufacturing and consequently affordable (as volumes increase, the cost per unit decreases).

Its anti-ice and anti-fog properties may improve, among others, the usability of indoor and outdoor interfaces for infrastructures or residential environments. Bending and folding do not affect the material's performance and it may enhance the response time (sensitivity), image quality, and energy efficiency of touch screens, which are becoming increasingly widespread on a global level for use as control panels or components for consumer electronic goods (Fig. 3).

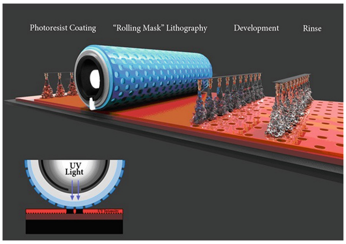

Fig. 3. The Rolling Mask Lithography® (RML) manufacturing process [21].

4 Safety-Improving Programmable Materials

Recent key findings in the field of forefront material solutions include pre-programmed engineering magnets suitable for designing items from lightweight wearable devices to components for industrial use. The company Correlated Magnetics Research LLC develops and manufactures a new generation of machinable smart magnets under the name of Polymagnets® [22], offering the possibility to regulate with high accuracy not only the function, but also the feel individually. Opposed to standard rare-earth magnets, Polymagnets® are programmable and enable a different level of control over polarity in a single part through the combination of multiple magnetic fields; they are imparted precision auto-alignment features through a patented method involving the application of Barker correlation codes for programming the magnets [23].

These intelligent magnetic materials have minimized interference with sensitive electronics and are capable of holding with relevant force and perform a variety of standard and specialty mechanical functions, such as latching, springing, holding, snapping, aligning, twisting, torqueing, releasing or softening, thus constituting a dynamic tool for engineering safe and easily operated closures and further components for sensory and mobility challenged end users (Fig. 4).

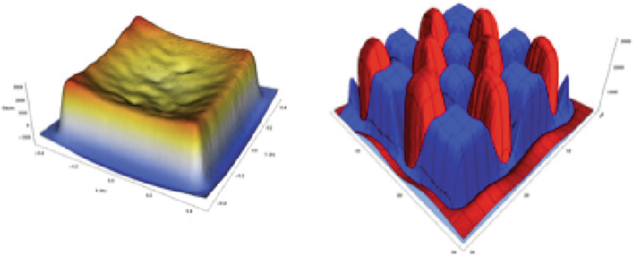

Fig. 4. The graph on the left shows the typical field coming off from a standard rare earth magnet, featuring only one north and south. The graph on the right illustrates the field of a Polymagnet® with a complex checkerboard pattern of north and south poles responsible for its advanced functionality [24].

The implementation of the selected products is aided by novel authentication and tracking systems capable of ensuring the origin of materials, parts and products, and safely store reprogrammable or permanent, uncopyable information, as is the case of tagging systems applied molecularly [26] to materials and developed for simplified integration into a wide range of carriers (Fig. 5).

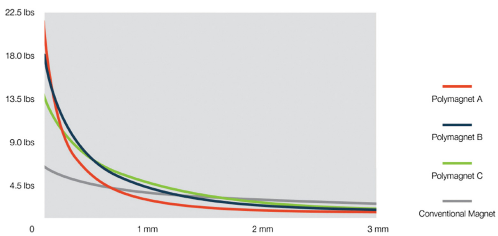

Fig. 5. The graph shows a comparison between a conventional magnet (*0.010" steel = grey*), whose very far reach generates a force that causes the parts to snap together abruptly, and Polymagnet® types (*A = red; B = blue; C = green*), whose adapted field creates a focused force that induces the product to come together more gradually and hold securely [25].

Permanent anti-counterfeiting tagging improves the safety of systems and environments as it ensures the authenticity of the components and products adopted in order to support different levels of independence.

5 Conclusions

The findings of this study suggest that state-of-the-art material solutions, among which are nanomanufacturing and advanced AM technologies, represent cutting-edge design tools for the devising and engineering of human diversity-tailored intelligent systems and environments at a level even beyond meeting current standards and complying with applicable regulations.

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