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Leveraging AI in Concept Development for Textile-Based Wearable Healthcare Devices

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***Abstract*—This paper describes the design and implementation of AI techniques to help engineers and designers alike narrow down the implementation of functional design elements, and how those can be translated into conceptual sketches and 3D models. AI can help validate shorter and more dynamic development cycles for a quick refinement of concepts, and can provide more fluid communication with stakeholders throughout the design process to ensure successful prototype development and client buy-in. The comparison and combination of traditional concept development processes and new AI processes can expedite the workflow, making it more adaptive, data-driven, and aligned with the unique demands in the biomedical engineering field.**

Keywords—concept development, sketching, textile-based wearable healthcare devices, AI

I. Introduction

The development of textile-based wearable healthcare devices has seen big leaps over the past thirty years primarily to major advancements in technological research, in prototyping technology, and additional knowledge gathered in materials science, electronics, and user-centered design. The development of medical wearable solutions, ranging from smart garments and portable devices that monitor vital signs, all the way to compression fabrics with embedded sensors, has transformed patient care by enabling real-time health tracking and personalized treatment options. However, the success of such devices depends heavily on a well-structured concept development phase, where industrial designers play a crucial role in shaping both function and user experience.

Historically, industrial designers approached the ideation phase with a hands-on methodology, relying on sketches, paper models, and marker-rendered iterations to explore form, ergonomics, and usability. Initial mock prototypes, often crafted from simple materials, allowed for rapid testing and refinement before committing to more complex development stages. This physical and iterative process is mostly understood as a process that is "inexpensive and can be done relatively quickly" [1].

During this important phase, it is essential in addressing challenges such as flexibility, durability, and integration of electronics into soft materials. Over time, organizations have carefully chosen visualization tools to support the phase of idea creation, or ideation [2], given that digital technologies have changed significantly in the last ten years [1]. Designers now have the freedom to choose tools and media to communicate visually, as well as choosing appropriate prototyping to supplement traditional methods [3]. Yet, the importance of tangible, early-stage exploration remains fundamental in ensuring that textile-based healthcare devices meet both functional and human-centered design requirements.

This paper explores the evolution of the concept development phase in wearable healthcare design, highlighting the role of industrial designers in refining ideas through iterative prototyping and traditional sketching techniques. By examining how this process has shaped the field, we can better understand the continued need for balancing physical experimentation with emerging digital tools in the design of next-generation textile-based medical wearables.

II. Literature Review

A. Use of AI in Developing Concepts in Wearable Healthcare Devices.

In a seminal article written by CEO Austen Angell in Innovation magazine, the publication of the Industrial Designers Society of America (IDSA), he explored the intersection of artificial intelligence, design thinking, and the evolving role of designers, particularly in healthcare and wearable devices. He questioned whether AI could replicate the unique ability of human thinking in a nonlinear, intuitive nature, called think-slicing, saying that "design thinking methodologies allowed the team to redefine and explore the problem in a nonlinear way that optimizes a positive human outcome." [4]. Additionally, beyond being able to process vast amounts of data and patterns, perfecting this think-slicing in a way that could mimic intuition. However, Angell highlights a crucial limitation: AI lacks the capacity for true empathy, which is an essential element in designing effective healthcare solutions, as well as raises concerns about AI's role in healthcare, with data privacy and the ensuing ethical concerns. At this point, designers, Angell declares, must be the ethical stewards especially when there is the potentiality that AI might deviate from the primary directive of human survival.

In the 21st century, wearable technology has seen remarkable advancements, particularly in health monitoring. Wearable sensors have evolved from single parameter monitors to multi-parameter systems that provide more comprehensive health data points. Early developments included bed sensors for elder care in 2008 and intelligent bed sensing systems in 2010 [5]. By 2012, smartphone-based fall detection systems emerged, followed by multimodality fall detection systems in 2013. RFID temperature sensors were introduced in 2014, and in-ear heart rate monitors came out in 2015. 2016 saw the advent of comprehensive IoT smart home health monitoring systems and unobtrusive sleep monitors. Additionally, the recent development of smart textiles includes embedding sensors into clothing to track physiological data in real-time. In the commercial market, other wearable devices such as fitness bands, smartwatches, e-textiles, and implantable sensors now use technologies like Bluetooth, RFID, Wi-Fi, GSM, and NFC, and contribute to the broader trend of personalized health management.

B. Traditional Industrial Design Processes: Sketching and 3D Rendering Techniques used in Industrial Design.

Designing is a dynamic process that involves innovation, analysis, decision-making, and feedback [6]. It starts with creatively building the nature, appearance, and social function of objects, and as ideas are formulated, various elements and constraints are balanced, and mental images are externalized through sketches, drawings, and models. These representations help sort information and generate new ideas. The design process is solution-focused and goal-oriented, done in iterative cycles of trial and error to refine solutions.

Each one includes innovation, analysis, decision-making, and evaluation, with feedback loops to improve the design, until the desired solution is achieved, or resources are exhausted. Contrary to a scientific method, the design process is open-ended and ill-structured, with goals and criteria evolving over time, and solutions are assessed based on their appropriateness rather than being right or wrong. In this stage, hundreds of representations like sketches and three-dimensional prototypes are used [7] to identify, evaluate, and develop solution candidates, thus allowing designers to explore and structure problem-solution pairs effectively and quickly, so that ideas be communicated effectively with other designers or to show to clients [8]. In a traditional sense, the creation of sketches started with the use of tracing paper which allows us to work in iterations. In this stage only a few sketches are considered for the next phase, “Figs. 1 & 2”.

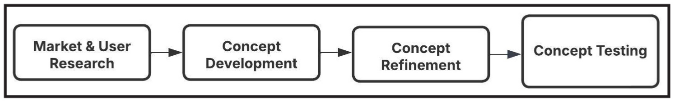

Fig. 1. Concept Development , Boot, Donohew, Wleizien, Wu.

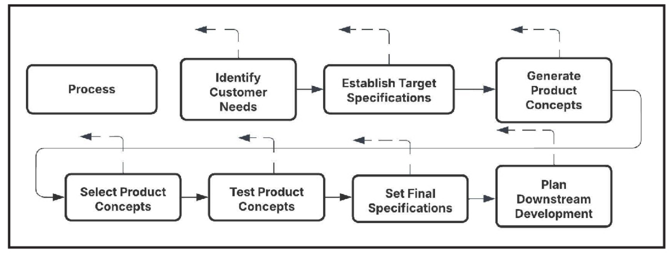

Fig. 2. Concept Generation Flow, Ulrich & Eppinger.

The role of industrial designers has changed in the last three decades, we see how they worked in isolated groups and were tasked to work by management with “putting lipstick on a pig” on products [6]. With initiatives like "Sketch Day" by the vacuum company Bisell, designers began working together and fostered a culture of shared ideation and cross-disciplinary engagement, using mostly pencils, gray markers and white paper. What started as an internal effort to boost design sketching, gradually drew-in engineers, model makers, and even patent attorneys, where everybody observed the process of communicating ideas in a comprehensive format. This signaled how design was transforming large organizations’ product development process, in alignment with business and engineering objectives.

III. CONTEXT OF STUDY AND METHODOLOGY

Undergraduate students majoring in Multidisciplinary Engineering and in Biomedical Engineering participated in the initial responses gathered from three classes: Human Factors for Industrial Design, Senior Design Project, and Design of Textile-Based Wearable Healthcare Devices. The evaluation criteria were based on the students' engagement and outcomes using various AI tools introduced during the academic year 2024-25. The assessment focused on measuring the level of interest and participation in using AI tools for concept development and observed how students adapted to AI-assisted sketching and rendering techniques. The initial responses, while did not have the number of participants to make a relevant determination of the efficacy of these tools, served to evaluate the quality and refinement of initial sketches and concepts developed using AI tools, and to assess the potential for conducting formal human subject research.

The initial response was overwhelmingly positive. The use of AI tools significantly enhanced their ability to fine-tune initial sketches, particularly for those without formal training in sketching or rendering techniques. This early success has provided a strong foundation for proposing an IRB form to initiate Human Subject Research in the upcoming academic year, with plans to involve a broader student base.

The preliminary implementation of AI in concept development for textile-based wearable healthcare devices has shown promising results, especially after seeing the enthusiastic student attendance of IDSA members on a Deep Dive lecture on Generative AI. The remote access of students highlighted the potential for further research and development in this area. Moving forward, a formal IRB-approved study will be essential to validate these findings and expand the scope of the research.

IV. TOOLS USED IN CONCEPT DEVELOPMENT

A. *Traditional tools used in Concept Development.*

For the last 20 years, designers have used marker paper, pencils, and designer markers, to convincingly reproduce an idea with shadows, textural notes and extra elements around [9], including the creation of concepts done with textiles and soft goods. The process involves finding the right point of view, working with lines, adding soft materials to represent fabric folds, and lastly, markers [10].

An evolution of the sketching style involves the shift from manual to digital media, but it can significantly impact the designer's workflow and creativity. When designers switch mid-process from traditional tools to digital tools such as laptops and mice, they may struggle to fully automate their process and might lead to a less fluid and cohesive design development, labeled as problematic segregation [11] and might hinder the designer's ability to seamlessly integrate the creative flow of ideas.

Given the recent technological advancements, designers often use a manual-digital hybrid approach, a change that has not been without challenges, as transitioning between one and the other can disrupt the design process [12]. Despite these, digital sketching tools, such as tablets, Apple iPads, Wacom Cintiq tablets, a computer mouse and the right design software, have become integral to the design workflow, and have enabled more efficient and precise iterations.

B. *AI tools in Concept Development.*

AI tools have significantly enhanced the efficiency and effectiveness of market and user research, by leveraging generative AI tools like ChatGPT, Bard, CoPilot, or Vizcom. Designers and trained engineers can quickly gather and synthesize vast amounts of market and consumer data, revealing opportunities and overlooked user needs, which would later lead to ethnographic interviews and additional design concepts.

In concept development, text-to-image generative AI tools have revolutionized the process by providing rapid, lifelike visualizations based on expert prompts. These tools inspire innovative ideas and accelerate the development phase, allowing designers to iterate quickly and efficiently. Despite this, human intervention is still necessary to refine and validate AI-generated outputs [10], but technology frees designers from time-consuming tasks. For example, an automotive OEM used AI to create 25 variations of a next-gen car dashboard in just two hours, a task that would have taken a week without AI.

Refining generative AI outputs is crucial, as text-to-image tools often produce flawed images [11], such as not believable body parts or sensors in the wrong locations, "Figure 3". Organizations should budget for substantial postproduction editing or going through further iterations, as usually the results require hours of adjustments, or in close inspection they reveal that they are far from manufacturable or useable.

Fig. 3. Failed CPR sleeve done in AI, based on a freehand sketch.

C. *Shortcomings and Challenges*

The implementation of AI raises concerns regarding the safeguarding of sensitive information, including data breaches, unauthorized access, and misuse. This might in turn increase regulatory scrutiny, which might discourage customer participation [13].

Over 40% of publications have highlighted ethical concerns related to privacy, security, and confidentiality in the context of medical devices, including the potential for inappropriate access and misuse of personal or sensitive information, even in the sketching stages, as well others, like inadvertent release of patient data, or de-identification of raw data input for AI algorithms [14]. Wearable healthcare devices are capable of continuous data recording and can collect extensive patient information such as body temperature, heart rate and sleep stages, and even in the concept development stage designers are to be cautious the kind of data it is collected [15].

There are other concerns on the process of sequencing writing prompts in AI, where the responses will vary largely depending on the contextualization and methodology used [16]. One way of completing a sequence is to start with beginner prompts with minimal experience, and then add subsequent and specific sub prompts, to refine responses as needed. A different method is to treat the whole process as a thoughtful experimentation, asking AI various questions, and if it makes a mistake, provide additional feedback like, "Try again, but with more enthusiasm," or "Redo this part, ensuring the math is accurate" [17].

V. Case Studies

A. *Body sensor sleeve for babies.*

Body sensor to monitor the temperature in patients with weakened or immune-compromised systems. It gives caretakers appropriate alerts every two minutes. It is designed for young patients from newborns to 2-year-olds and requires the placement of patches to read body temperature every few minutes. "Figure 4" shows the flow in the creation of concepts of this body sensor, from the cartoony approach on the left concept, to the photo-realistic impression of the second, and the sketchy solution offered on the third version. The photograph on the bottom right corner was not deemed usable to obtain a credible sketch in AI.

Fig. 4. AI-generated concepts for a body sensor sleeve, for 2-year-olds.

B. *CPR forearm sleeve.*

Device to be worn in the arm and in part of the hand, to be used during CPR compressions on adults. The built-in accelerometer helps users count compressions and maintain tempo, and the LEDs within the bracelet change colors to alert the user to correct tempo and when to switch to breaths, "Fig. 5". A variety of AI tools were used to unsuccessfully obtain a credible solution when the hands are interlaced for CPR compressions.

Fig. 5. AI-generated CPR concept, based on a photograph of a physically sewn prototype.

While not using sensors, this student project shows the capabilities of showing accurate wrinkles and the behavior of fabric in a body. This is a lightweight jacket for a three-hour car ride, conceptualized to transition from cold to warm weather, and with unique features such as a detachable hoodie and underarm zippers. It is envisioned to be thermally adaptable, lightweight and available in unisex sizing. The sketches left to right include a freehand drawing, which was used to obtain a refined AI concept, and later transformed into a high-resolution AI rendering, "Fig. 5".

Fig. 6. Jacket Design, for Human Factors for Industrial Design.

C. *Horse sensor device.*

This device was sketched as a research project that involved monitoring vitals of horses. The original sketch was completed entirely by hand (left center) and subsequently other sketches were completed by drawing digitally over a gray outline of a horse. Multiple sketches can be created this way, but the front strap is noticeably missing on the shown concept, "Fig. 7".

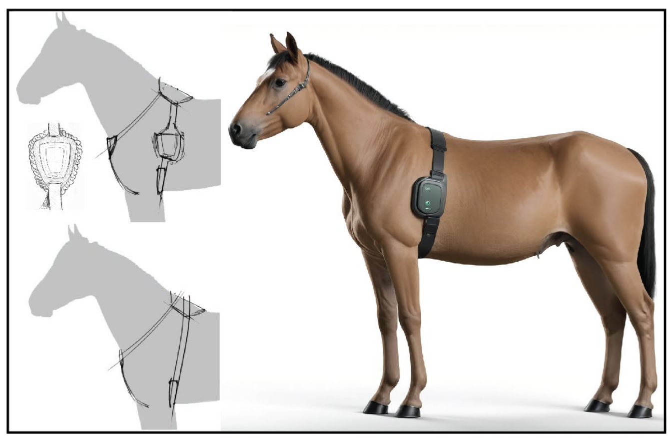

Fig. 7. Horse sensor device, showing an original sketch, consecutive sketches over a gray outline, and a final rendered concept.

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