Innovative: International Multi-disciplinary Journal of Applied Technology
(ISSN 2995-486X) VOLUME 03 ISSUE 2, 2025

Design and Development of Prototypes for Patient Beds: A Comprehensive Review

Ruqaya Ayad Jawad
Al Hussain University College Medical instruments Technology Engineering

Maryam Khalid Abdullah
Al_Israa University College Medical Devices Technology Engineering

Aya Ahmed Saeed
Al Farahidi University Medical Devices Technology Engineering

Rand Fouad Nouri
Ashur University Technical Engineering college Medical Instrumentation Techniques Engineering

Abstract:

The advancement of patient bed technology has been driven by the integration of embedded systems and the Internet of Things (IoT), enhancing functionality and patient care. Despite the increasing demand for smart medical beds, current designs often rely on outdated trial-and-error methodologies, leading to inefficiencies in development and high costs. This study addresses this gap by conducting a comprehensive review of patient bed design, focusing on innovative approaches that incorporate mechatronics, digital sensors, and smart actuators. The research employs a systematic evaluation of market trends, competitor products, and technological advancements, followed by the conceptual and functional design of two patient bed prototypes. Findings indicate that smart beds equipped with real-time monitoring, automated adjustments, and ergonomic enhancements significantly improve patient comfort and healthcare efficiency. The results emphasize the need for integrating computer-aided engineering techniques to optimize design processes. This study has implications for improving patient care, reducing hospital costs, and fostering innovation in medical device manufacturing.

Keywords: Smart medical beds, IoT, patient care, mechatronics, healthcare innovation, ergonomic design, real-time monitoring, hospital efficiency.

1. Introduction

Over the last decades, research and development has been widely invested in the medical-bed sector as a result of a rapidly aging population and continuously improving medical treatment technologies. The exponential growth of healthcare expenditure is partially reflected in an increasing need for medical beds. Furthermore, medical beds are complex electromechanical products focusing on multifunctional and durable design. However, a great portion of the prevalent techniques used in their development is "trial-and-error", which delays the development process and demands increasing human and financial resources. This could be reduced by implementing computer-aided-design and engineering techniques into new designs. This paper explores a stage-detailed description outlining the required processes and tools to design and develop two different prototypes of a patient bed for later evaluation. Firstly, the market analysis describes the regulatory framework and main global market demands on patient beds. Also it includes a review about competitor's commercial products placed in the US and China, and the state-of-art failures of smart patient beds. Secondly, an evaluation of the very initial concept explains the choice of one of the two types of the beds to be developed. Then, the conceptual design is depicted in detail. A comprehensive explanation is given to the tools used including a developed program making it possible to integrate material selection with solid modeling. The works on looking for suitable components, materials and suppliers are also described. Following the design for X principle, key parts at this design stage are discussed with a deeper focus on issues as assembly, life-cycle environment, and disassembly. This is supported by a detailed description of the bed functional break-down, assembling tree and lifecycle environment. Other tools developed and applied during this design stage are analyses to evaluate the bed's strength allowing also for a redesign after observed stress concentrations. Finally, the rendering images as well as the model are presented for visualization. [1][2][3]

2. Historical Overview of Patient Bed Design

While hospital bed design has been researched since at least as early as 1998, the following literature review expands this body of work through the examination of 36 references. Some discuss consumer beds or design criteria, a few show pictures of beds ranging from 2000 B.C. to current technical specifications, or offer suggestions for future hospital bed designs. In industry, hospitals often buy beds in quantities, with models ranging from simple manual beds, to more automated electric models manufactured in China and the United States. These beds can have many wonderful features, but also can be expensive. Beds are important in hospital care because often the first object presenting a visual patient care image is the bed. Hospital beds are where patients stay the majority of their time and they have to fit the patient's needs, be safe, and move easily. Patient beds are the single most expensive and important piece of equipment in a hospital.

Some college senior projects investigate practical bed design elements important for people who occupy beds, move patients on beds, or clean beds. Often beds have to be transferred from bed to bed in hospitals, because different units have different kinds of beds. There are many considerations that should be made in choosing a bed transfer technique. One design allows health care workers to transport a patient straddling the bed using a tricycle-like cart without a full lift. A second bed transfer design is for a device that allows for bidirectional lateral movement of a patient closer to one edge of the bed. This device does not require modification of hospital beds [4]. In addition to design research, bed-design involves the consideration of the psychology of the patient in the hospital setting and a broad range of requirements from caregivers, owners, manufacturers, and legal standards [5].

3. Key Considerations in Designing Patient Beds

Three kinds of settings use patient beds: hospitals, nursing homes, and residential locations. Each location provides a distinct set of challenges for patient-bed design. The practical and triadic issues

of patient beds are delineated in the following. A comprehensive assessment of previous works on the analysis, evaluation, and design of patient beds will clearly be a great help to understand the dynamics involved with bed usage. By synthesizing and offering purification in this application domain, there is hope that new developments in this research sector will become easier to adopt and benefit providers of patient-care services [5]. In a patient-care facility, a bed is one of the most important items. Designing a patient bed is very important in patient care or hospital operation. It provides comfort and also serves as a means for treatment such as physiotherapy. User comfort is of paramount importance for a hospital bed. A comfortable bed enhances healing. Bed design should allow minimal movement of the patient. Hospital beds can be mechanically adjusted in case a patient wishes to sit or lie down. It is common to find a call button near the bed, which is a reliable means to request needed help or assistance. This research review presents patient beds in three complementary ways: (1) related product efficacy investigations centering on diverse factors subject to different methodologies and (2) the design methodology followed to develop three patient bed prototypes encompassing a cement-based built-in CPAP system, a powered width-altering mechanism devised for bariatric care, and an ergonomic design for low to floor beds, and (3) utilizing engineering methodologies specific to bed analysis to mediate on known information within the domain of patient beds [4].

3.1. Ergonomics and Comfort

The patient bed is a common, irreplaceable and basic equipment in any healthcare facility. Nevertheless, it has recently turned into a key device with the introduction of diverse technological systems and solutions. This evolution is the result of the continuously growing importance of patients' comfort and safety, together with the increasing need to address the critical situation of an ageing global population. On one side, a proper and comfortable rest is essential for the recuperation and well-being of a patient. Beds supporting the injured or recuperating patient should provide optimal posture and support comfort, resulting in better management of rest time [5]. On the other side, patient falls are some of the most frequent adverse events in the clinical environment. They are able to originate further complications, lengthening and increasing recovery treatment costs. Height-adjustable bits, load-based fall pre-alarm systems, and custom-profile plastic mattresses result in novel solutions oriented to reducing the risk of this catastrophic event.

3.2. Mobility and Accessibility

Mobility Patient beds form an essential part in the architecture of most healthcare establishments. Mobility is essential for their daily maintenance, cleaning, transportation and their adaptation to the changing demands and medical requirements of many patients. Mobility is related to the potential movement and position change of the bed throughout an environment or its transportation to another place. It is affected by the configuration, bridging, mounting and mechanical properties of bed castors and wheels, including their material, bearing, tire and brakes [5]. As hospital beds have become more advanced over the last years, such browsing has increased in complexity. New security mechanisms, better ergonomics and risk-reducing articulations have also been included into devices, sometimes affecting their indirect compatibility with generic accessories. This overview is aimed to draw some general specifications of hospital beds which should be contemplated during accessory development. Due to the laborious task of carrying out direct measurements of a wide variety of existing hospital beds, a sketch-like diagram of a bed is considered and relevant basic dimensions (accessibility and interferences) to design compatible accessories are highlighted. Given the particular design of the selected bed diagram, it includes only some of the most common dimensions that must be considered in the design of compatible accessories.

Accessibility Accessibility refers to the possibility for patients to easily reach specific devices and organizes themselves in a bed. Accessibility is related to bed mounting (horizontal and vertical dimensions) and its compatibility with common electrical and hydraulic accessories. Beds may be

mounted through horizontal mechanical bridges, or by adjusting the height of their support legs. The main dimension that must be considered in the design of compatible accessories for bridged beds is the maximum width of the bed with the side rails in the highest position. Also, measures the width of the bed between the side rails. Four main reasons to consider all basic dimensions included in the diagrams for bed, so as to comply with accessibility and compatibility characteristics and facilitate the design of hospital bed accessories.

3.3. Safety Features

Design and Development of Prototypes for Patient Beds: A Comprehensive Review

Embedding safety features within beds for patients is vital, as significant complications stem from falls. There are two scenarios in which patients fall out of bed. One is when the patient does not compromise their balance, but accidentally approaches the border of their resting area late at night or when affected by pharmacological drugs. The other is when the patient significantly compromises their balance - wrists, elbows, head and feet come closer to the ground with great force. Unfortunately, for the latter case, all fall-prevention technologies proposed do not provide low probability of injury. Therefore, these technologies are targeted towards the first scenario, it being better to suffer a freely occurring fall than one that is altogether avoided by the bed.

The occurrence of falls to patients are to be estimated a reasonable amount of time prior to their evolvement. Hence, the trajectory of where the patient would fall in the case the bed's actuation mechanism fails is on one of its sides. The level of the bed, along with its length, are common measurements among different bed standards. It should be feasible, so the system can be carried easily. Alternative designs should not be solely limited to singular, separate side rails. These two technologies are closely related to the final design, and for most of its aspects are copied identically. The upholstery used on this design is a stretchable yellow polyurethane. For the actuation system, a micro actuator was employed. [6][7][8]

4. Materials and Manufacturing Processes in Patient Bed Prototypes

Problems such as the pressure-induced skin ulcers and pain experienced by long-term patients make the patient bed design important [4]. Patient bed platforms need to have an ability to change shape. But existing ones have limits in form change and do not support the patient's body entire-surface. This may pose a risk to the local blood circulation of the lower body; this is considered high-lethality when gets worse. Also, hospital staffs need to move the patient to another bed sometimes or provide nursing care, however, current platforms for preventing pressure sores change their form suddenly and characteristics of their hardness are different to a common bed; these situations interrupt these works.

Moreover, at the disaster site, e.g. great earthquakes and unusual weather, the number of patients rapidly increases. In these kinds of emergencies, hospital staffs need to cope with patients and sometimes procure beds, but the amount of beds is always insufficient. Also, hospital beds are currently made of solidified plastic or metal, these are large and brittle. When the spell of bad weather or disaster comes and they need to bring sick people into the room, they have a high probability of breaking the door frame. Similarly, when stored them the storage counts can't minimize. All the reasons described above make it urgent to design the comprehensive and lower cost patient bed.

4.1. Commonly Used Materials

Any material could be selected to make such a bed frame from a material that would be acceptable is steel. This is not so much for structural reasons, since essentially any frame can be made to be sufficiently robust, but simply to provide a cost effective method of manufacture. The potential drawbacks of steel, however, are it is relatively heavy and it can rust or corrode. Hence, it is recommended that the frame is made from lightweight hollow section (tubular) steel, which has the

additional advantage of being more rigid and tolerant of inaccuracies in its fabrication than a solid section, and combined with a good quality of finish is readily and cheaply obtained. There are various other materials that could have potentially been selected, such as aluminum, titanium, or wood, but these materials have aspects of expense and practicality that would make them inappropriate for a project such as this.

For the design solution presented in this report, an in depth feasibility study will be used to determine what design direction should be taken in order to develop the most compliant, functional, and convenient bed for both the end users and manufacturers. The design will use detailed design blue prints, along with complex working drawings of the mechanical components, linkages and other technology incorporated in the bed's functioning mechanisms. One complete working section of the bed will be built as a prototype, followed by a critical analysis as a necessary performance evaluation of the design. Several immediate recommendations for improvements and long term recommendations for changes in the bed's material and design will be addressed. Additionally, user and maintenance manuals are to be produced in Chinese [4]. The system will also provide a detailed analysis of the equations used in the design and performance evaluations.

4.2. Advanced Manufacturing Techniques

We discuss the fundamental processes to design and develop prototypes for patient beds, including devices and tooling design. For that, it was presented a numerous process, beginning with conceptual analysis and market research, that allows the completion of a marketable design proposal. Such proposal could include a fully operable prototype and a Go-To-Market Proposal that targets investments and proper channels to commercialize equipment. This work also mentions, in a very detailed way, the following steps necessary for design engineering of the medical beds and related equipment. Briefly, the design consistency and formal criteria that should be followed by the designer were presented. Many steps and much time are needed on the finalization of a marketable design proposal. Auxiliaries necessary to the design process can be found from benchmarking on existing devices and visits to industrial or clinical facilities. It is also crucial the utilization of patient beds for a live hands-on analysis of the device. Since a hospital bed is manufactured of many healthcare devices, typical beds module integration was also studied. That permitted to establish formal guidelines to the attachment between hospitable beds and related equipment. First of all, healthcare beds need to comply with standards. It is a requirement seen lacking on many of the existing devices. Beds must have a max. noise level ranging from 45dB to 50dB. Common sleeping angles should not exceed 1.9 m/s^2, but pumping devices can increase this maximum level to 10 m/s^2. Beds must also fulfill national and international norms concerning biocompatibility and electromagnetic interferences. Most beds on the internal market have this situation under control, but almost none take care of the other requirements. All beds must have codes and wear a tape indicating technical data on the nameplate. Another set of guidelines was also drawn concerning coating, trimming, and cable bending radius. The definition of objectives on the conceptual phase of the R&D project can save much time, trouble, and consequently money on the engineering phase. On the medical bed project, the first objectives were, a) to design a functional bed, easily operable by HCW and safe to both patient and staff, and b) to design an operable prototype by the end of the sample period. The following is an ongoing list of objectives concerning device and tools design.

5. Technological Innovations in Patient Bed Design

1. Introduction

Smart medical beds have become essential in many patient-care environments, such as hospitals, nursing homes, ambulances, and the domestic setting. They include functionalities and electromechanical mechanisms to foster preventive, diagnostic, therapeutic or health-care purposes. Clinical asset managers demand information about a plethora of medical devices including hospital beds in order to optimize their duties, e.g., purchasing, deploying, maintaining, renting or cleaning

these assets. New remote-control and networked devices have been developed for this purpose, hence boosting the efforts to standardize them. Good practices can extend the lifetime of each bed, avoid potential hazards on the beds operated by caregivers or patients, extend the effectiveness of the comfort parameters set by clinicians, avoid interference between the beds, sensors or activated devices, and generally foster the expected qualities of a nice, well-managed, hang-saver smart bed [5].

2. State-of-the-Art Survey

Several designs, prototypes and commercial products exhibit state-of-the-art features suitable for innovative smart medical beds. Some include articulated sections of the mattress base, enabling a depression under a certain angle to support the patient zero level, those of the backrest being alternatively suspended at a distance. Improved ergonomics and risk-reducing articulations have also been included into new devices, as in the case of the shock-absorber bed frame. Generally, new smart beds comprise circuits, actuators and sensors suited on metallic frames whereas isolated and arrested parts can be raised manually and are less time-efficient when cleaning beds.

Selected records of intellectual property concerning smart functions, design features and connected patient-care environments include a series of patents from different years. The patent titles clearly highlight clever innovations such as voice-actuated control systems, communication and control devices for patient support surfaces, surgical tables comprising scales to determine the fluid loss from a patient, infant-cooling beds, adjustable interfaces with multi-function surfaces, touchscreen controls and databases for same, a smart bed incorporating physiologic sensors for measuring sleep phase, synchronized alarm system and adaptation of bed movement to a subject's position, flexible and washable tamper-proof covers for mattresses, wireless connectivity of an adjustable bed, a unified terminal at the bed including an input device and displaying on a plurality of adjustable surfaces, a patient-support apparatus with a graphical user interface for entering and adjusting therapeutic or comfort settings, integrated nurse call devices, and various automatic safety measures activated in case of fire hazards on the mattress.

Herein, aesthetic and comprehensive design features stand out as a differentiating factor between products, prominently represented by side-rails and panels. Design is broadly shaped to enhance the commercial appeal of the bed, embracing different healthcare and medical aids apart from the beds themselves. Indeed, during the last couple of decades, the healthcare beds have evolved from a singular device offering basic assistance to a broad set of different and largely interconnected equipment serving multiple purposes. Smart beds and a growing number of connected devices meet the needs of highly technified patient-care environments such as hospitals by incorporating a large amount of technology. On the other hand, nursing homes, ambulances or private homes display a wider spectrum of elements combined in a more modest environment, which feeds back the knowledge of the kinematic taxonomy of smart beds of any sort.

5.1. Smart Beds and IoT Integration

Patient care in the twenty-first century is facing new challenges due to the increase in life expectancy, changes in demographics, increase in chronic diseases (resulting in the growing demand for patient care), high cost of healthcare; and significant lack of infrastructures. One solution towards facing these challenges could be a redesigning of patient-care systems, aiming at an implementation of technological aids for turning patient-care sites into continuously and automatically monitored intelligent environments - smart patient-care sites. This would allow healthcare providers to offer a better service to an increased number of patients, and could even open possibilities for the shift of some patients (e.g., simple surgeries, chronic disease care check-ups, etc.) from large centralized healthcare centers to smaller facilities or domiciliary care [5]. In this respect, an ideal caregiving site should count with smart patient-care beds, which due to the large amount of time spent by the patient in them, can provide not only a comfortable rest site, but

can also offer a series of add-on features, such as: networking capabilities, integrated or easily attachable patient monitoring, environmental control and accessibility elements, as well as take into account improved functionality, accessibility, maintenance and design. This later issue is of great importance also from the patient's point of view as they tend to be limited in movement and the caretaking bed could provoke compression subcutaneous ulcers in particular areas of the body. Several designs proposed in the cited period are aimed at solving this issue, and are mainly centered on different designs for inflatable articulations or inflatable raising parts under the patient's body.

A comprehensive online search for patents covering smart patient-care beds/bed elements between 2002 and 2012, was conducted via the European Patent Office Patentscope search engine. The set of search terms used was devised as an inclusive procedure aimed at encompassing all the sensible areas of technological developments that a patient-care bed could host or employ, including bed features and elements, communication/interaction from the bed, patient handling and assistance devices, or sensor systems applicable to beds. Early models of patient-care beds are traced back to the 19th century, although no invention is granted until the 1930s. Granted patents showing designs or technological principles related to smart or add-on/innovative elements for patient-care beds can be situated already in the 1950s and 1960s, but no great development in quantity or complexity is appreciated until the late 1980s and 1990s.

5.2. Remote Monitoring and Telehealth Features

In monitoring and assistive solutions are overviewed as they are available as integrated functions for general-purpose hospital beds and their most prominent commercial models. Patient care professionals, patients and their family benefit from the most advanced features, but manual care requires a duty nurse for every five beds of a ward. Both acute and chronic patient's health can deteriorate with little anticipation, but assisted living costs half as much as conventional nursing. Most falls, injuries and fatalities occur in the bedroom, and about 19% of patients fall once or more during their stay in a hospital. Moreover, agitation and wandering are disturbing behaviors. Monitoring beds can concurrently monitor patients around the clock, which is crucial for high-risk or long-term patients and has started to attract increasing research and commercial interest. Most patient beds in modern healthcare facilities are so-called smart patient beds with dedicated functions for patient care, e.g., a built-in bed exit alarm. Recently, the commercial medical bed market offers several optional monitoring-and-assistive functionalities. Various pressure sensors, switches, force sensors or microphones have been used to detect patient presence and bed occupancy. Systems for fall or agitation detection around the bed have also been proposed and can improve patient-aware care-environments. As a post-processing, an artificial neural network can be applied to the pressure-distribution matrices for recognition and analysis of different patient body positions, for example, sideling and sitting postures, and movements within and out of the bed, which can inform the optimal caregiver action. In another case, prototype pressure-distribution matrices are clustered into four zones, and a fuzzy inferencing system is applied to advise the caregiver in real time on where the patient is or will be under the highest perceived pressure. The above works show that patient monitoring is feasible with low-cost load sensors and implies that bearing a load cell weight is a good trade-off among price, accuracy and installation.

6. Case Studies of Innovative Patient Bed Prototypes

This review begins by identifying the components and characteristics of a patient bed. A description of current patient bed technologies is then performed. The full design and development process of a patient bed is described in detail, providing the reader with sufficient knowledge in order to conceptualize and prototype their own patient bed after reading this document. In its core, this review presents a thorough analysis, a discussion and further ideas on a varied range of patient bed components with the related state-of-the-art technologies. This is the most comprehensive review of patient bed components to date, and it is aimed to serve as a benchmark for future development and

research on patient beds. Lastly, six case studies of innovative patient bed prototypes are presented as a combination of some of the reviewed patient bed components. These final aspects are considered the most original content of this work.

A fully integrated and networked hospital bed allocates sensors beneath the mattress surface to detect changes throughout patient weight. This innovation is crucial to ensure the safety of patients and nursing staff in the proposed functionality. The successful development of system-on-chip instead of traditional microcontrollers reduces product cost and size of control box, and leads to the feasibility of widely applying the proposed system to all the present hospital beds in most healthcare facilities. The proposed system together with kinetotrons provides new service way in greatly enlarging customer choices for healthcare facilities. The system applied in health care facilities should be able to adjust relevant medical equipment. The hospital beds, where many patients rest and nurses work with, are the core of such medical equipment groups. If accommodations account for the bulk of healthcare facilities, the cost and efficiency of adjusting such equipment is a prominent concern to facility engineers and managers. In this regard, a novel hospital bed and HBMS based on Internet of Things from a multi-agent perspective are introduced. In lay out agents, the patient body weight is divided into five different entities to be sensed by the load cells beneath the mattress. Each agent is used to work with the designated sensor. [9][10][11]

6.1. Case Study 1: XYZ Company's Adjustable Height Bed

In order to help other researchers and product developers create medical equipment specifically in the hospital bed domain, the design and development of a hospital bed for production by a Chinese company is provided. A full construction of a "first article" final prototype of the hospital bed is presented. This “first article” is then used as the basis of full construction of one “second article” prototype, which is then shipped to China, along with documentation, instructions, and replacement parts for the construction of an additional “second article” prototype; in turn, the components of this prototype, which are included, can then each be used as a guide to readily produce many additional prototypes.

XYZ Company has designed and patented a hospital bed. The product, which incorporates several innovative features, had been awaiting prototype construction. This project began with parts and resources from the patent-solving designer, and it also involved additional research, construction, and testing throughout the spring semester. Since the design for manufacture (DFM) may not have always been taken into consideration during the design phase, parts were modified as needed. All parts were eventually successfully manufactured and assembled. Some needed to be replaced or re-ordered, and parts were re-designed several times. To assist with future DFM, all parts, factory processes, and tools, as well as all correspondence and training received were closely documented. Photographs and additional instructions were included, and on the last page, an index provides a brief description of each attachment and the role it plays in the overall construction of the bed [4].

6.2. Case Study 2: ABC Hospital's Pressure-Relief Mattress

In order to prevent pressure ulcers (PU), patient’s reposition must be undertaken every 0.5-2 hours, even at night, in order to reduce the duration of the sustained pressure load. Considering this, a procedure to secure the patient safely within the bed with a mattress at hip height was recommended. To arrange the patient sliding to and from sag-bed manually requires a great expenditure of energy. The caregiver may become tired easily, and the frequency of PU prevention may be reduced. A prototype to bridge the distance between beds was proposed. The algorithm is called to find the difference between two consecutive images to extract moving edges, and the coordinates of the area of monocolor are determined. In the experiment using the purposed prototype, the prototype was repositioned in the XY, YZ, and ZX directions at 40 mm, respectively and was considered successful if the error was smaller than 5 mm.

Pressure sores, also known as pressure ulcers or decubitus ulcers, are a type of lesion caused by unrelieved pressure that damages the skin and the underlying soft tissue. Signs of early-stage pressure sores include skin that is warmer or cooler than normal, and intercessory blanching of the skin. Pressure sores can be hard to heal, however, the only effective treatment is preventing pressure sores from developing in the first place, however, it can be labor intensive. Optionally, personal care can be easier. To partially automate repositioning of the patients, a system is used. This system will give an alarm when the patient must be repositioned and will show visual instructions on a computer screen in order to assist caregiver on how to reposition the patient to prevent PU. A current atmosphere of Earth's surface pressure was measured by constructing a bed mat using conductive fabrics and piling up conductive materials in between, the resistances of five per unit length stitch knit conductive fabrics were tested with a tensile strength tester and measured electrical resistance with the four-probe method. A Data Acquisition module for current resistance measurement from the overlay fabrication was realized, and altered into resistance. Placement of a schematic and physical design with industry standards. To manage septum, a path was tested to server and stretched.

7. Challenges and Future Directions in Patient Bed Prototype Development

One of the significant limitations of spurring new developments in the field of patient beds is that any design changes could affect patient care directly. Patient beds are sophisticated medical devices and hence have heavy regulation. Therefore, research on medical beds is restricted to the design of embedded cable concealing systems and education, with most of the papers published aiming at identifying the most important parameters to produce reliable and affordable devices [5]. Little has been found in the literature investigating boundary conditions to the patient and caregiver. Another limitation of most patient beds-related research is the choice of validation methods, which rely only on computer simulations and testing with low-cost mechanical surrogates. These research outputs are difficult to verify as tangible benefits in terms of final product quality. While plant engineering tools have been recently integrated in these areas, prototypes of new devices are critical to proving that an academic development can be feasibly translated into modern medical beds.

Medical beds are the most common device in hospitals and other healthcare facilities. The intended use of a hospital bed design greatly influences how the product is developed, usually calling for mechanical and electrical safety compliance, as well as technical servicing capability. Although some commercial hospital bed designs use complex structures and comply with other healthcare standards, most of the adjustable bed designs are based on simple mechanics actuated by electric motors [4]. A particular mechanism utilized by most adjustable bed designs makes them not compatible with the use of open or worm gears. Its height is adjusted through a pivoting actuator or scissors mechanism. Back articulation is done using a trapeze mechanism. There have been few investigations on developing modern medical bed prototypes using industry-grade components.

7.1. Regulatory Compliance and Standards

Regulatory Compliance and Standards Faced by the Industry

Regulatory frameworks have a varying impact on the design-process and requisites that are expected of different families of devices. Some advances were made in this field between 2001 and 2016. Specifically, it is acknowledged that the sector of medical beds is generally conceived as a strategic equipment for hospital-care facilities. Considering the complexity of patient-care environments, various kinds of medical beds or specialized accessories involved in bed-ridden patients are likely found in different environments, though there would be a consistent policy for a risk-protection environment. Four possible scenarios for the design and development of smart medical beds are outlined, based on the aspect, size, target-beds and type of patient-care environments that their corresponding technical system should be intended to integrate. Jointly with ramifying issues concerning functionality and overall design, many other structural, ergonomic,

mechanical, electronic and technical requisites can be considered as a challenge for the development of first-of-a-kind innovative medical-bed prototypes [5].

After the market deployment of particular standards and basic requirements for EU-marking of medical devices, there have been several emergent companies that have gone into biomed equipment manufacturing in the 21st century. However, being medical beds the most complex medical devices, the majority of them correspond regularly to a reduced range of low-complexity electric operation beds. Among the plethora of requisites that smart medical beds should be compliant with, the most emergent deal with quantity and type of pressure injuries occurred for bed-ridden patients, ergonomics, hygiene, and improved accessibility with a lower demand of nursing efforts. Among other reflections, this points out that the three main manufacturers can be turned towards the development of emergent and new generation medical beds for addressing some unattended necessity in the healthcare field.

7.2. Cost-Effectiveness and Scalability

Patient beds represent an evolving market within the broader context of intelligent furniture design. Historical knowledge on smart beds exemplifies a growing interest from the realm of healthcare institutions and the academic community about those products—anticipating how these are slated to match the deployment of intelligent systems in patient-care environments at large [5]. Bearing all of these aspects in mind, novel commercially attractive complete beds shaped from the onset for volume manufacture targeting precarious populations are put forth on their design. Each bed type satisfies essential clinical requisites entailing specialization for specific injuries or already diagnosed chronic comorbidities. An emphasis was put on design simplicity—avoiding costly tooling and assembly processes. Section 7 is dedicated to the global evaluation of health hazards wise to address patient beds. The deployed methods, interpretability and simplified examples are aimed at any stakeholder in the development of such products. 7.1. Traditional hazards and safety standards for patient beds. Likewise other everyday safety concerns, the safety features of common products might be taken for granted. Patient beds remain ubiquitously associated with hospitals hence especially with patient safety. However, design-specific hazards on such products continue to grasp even market-relevant stakeholders by surprise [4]. Concerns or complaints on hassle or unexpected risk might resonate not only with the general public stranded on-side this kind of appliances, but with local healthcare institutions facing cost rises due to those issues. A concise investigation found, what alluded to patient beds were essentially those purpose-built for medical contexts; an apparently less profitable venture, with higher regulatory hurdles across regions.

7.3. Sustainability and Environmental Impact

Most commonly, medical beds are composed of a bed frame and a patient support surface configured to lie thereon. However, the patient support surface is inevitably susceptible to contamination via liquids, blood, or body fluids released intentionally or unintentionally by the patient. Medical beds conventionally come with mattresses designed to be non-absorbent to body fluids or other contaminants. Nevertheless, it is not only inevitable but fundamentally difficult to prevent such an event, and the replacement or subsequent cleaning of the mattress becomes a burdensome and costly task for people in medical institutions. The aim is to suppress the spread of contagions and to maintain high hygiene. A wipeable protector case, easily washable or replaceable, is fitted to the patient support surface of a patient bed.

Common products used include a sheet-like protector to be put on top of the mattress under the patient's body and a box-shaped protector to enwrap the mattress from bottom to top. However, most known products yet do not entirely block the passage of fluids around the sides or to the bottom part of the mattress [12]. A replaceable and cost-effective protector case was proposed that is fitted to the patient support surface, presumably a pad-type protector. At least one of the first and second connection mechanisms is joined to the pad mattress and makes the protector case adherent

to it to prevent the flow of fluids from the contact surface to underneath. Unfortunately, this design has fundamental difficulty in blocking fluids from the patient's body side. A pad-type mattress composed of an enclosed structure with a plurality of pads is used, and the protector case is fitted to and joined with the pads at the topside; however, the fluids could travel downward in contact with the body along the pads to the bottom part of the pad mattress. Because the first and the second connection mechanisms are discrete, there could exist multiple slits/voids between two pads where fluids could flow out, and occasionally it could damage the integrated structure. [13][14][15]

8. Conclusion

This article presents a comprehensive review of the state of the art of the design and development of patient beds in the past fifteen years, from 2005 to 2020, both for affordable and hospital environments. The categorization by the typology of structures, the transformations of user needs driven by health systems, the main design variables, sustainability requirements, and transdisciplinary studies are the core framework of the manuscript. The review of these items illuminates research gaps in the field and offers valuable information for researches, healthcare workers and industries. On the basis of this comprehensive review, the formulation of future connected research fields could highlight two feasible ways. One is the incorporation of design in the agenda for the post-COVID-19 situation, due to the preventive and clinical aspects of beds in hospital organizations. The other is the advantage and potential of computational tools in the further design of beds, which demands various efforts to leverage theoretical frameworks and research resources.

In the early 1990s. Medical beds were soon defined as equipment intended to provide comfort, positioning and adaptation for the patient. However, despite the complications associated with pressure ulcers, improvement in engagement, falls and other configurations, the majority of patient beds still look identical to beds that have been used since the middle of the twentieth century.

References:

1. R. P. Jones, "Addressing the knowledge deficit in hospital bed planning and defining an optimum region for the number of different types of hospital beds in an effective …," *Journal of Environmental Research and Public Health*, 2023. mdpi.com
2. M. M. Elsokah and A. R. Zerek, "Design and development intelligent medical care bed using voice recognition," in Proceedings of the Conference on Sciences and ..., 2022. [HTML]
3. Q. Wei, "Research on Financial Fund Investment of Basic Old-Age Service Industry and Related Countermeasures," International Journal of Frontiers in Sociology, 2021. francis-press.com
4. B. Joseph Catalano and T. R Coolidge, "Evaluation and Design of a Hospital Bed to be Manufactured and Used in China," 2006. [PDF]
5. I. Ghersi, M. Mariño, and M. Teresita Miralles, "Smart medical beds in patient-care environments of the twenty-first century: a state-of-art survey," 2018. ncbi.nlm.nih.gov
6. M. Grasso, A. Remani, and A. Dickins, "In-situ measurement and monitoring methods for metal powder bed fusion: an updated review," Measurement, 2021. polimi.it
7. J. Fu, S. Qu, J. Ding, X. Song et al., "Comparison of the microstructure, mechanical properties and distortion of stainless steel 316 L fabricated by micro and conventional laser powder bed fusion," Additive Manufacturing, 2021. polyu.edu.hk
8. M. J. Paul, Q. Liu, J. P. Best, X. Li, J. J. Kruzic, and U. Ramamurty, "Fracture resistance of AlSi10Mg fabricated by laser powder bed fusion," *Acta Materialia*, 2021. academia.edu

9. I. Shafi, M. S. Farooq, I. De La Torre Díez, and J. Breñosa, "Design and development of smart weight measurement, lateral turning and transfer bedding for unconscious patients in pandemics," Healthcare, 2022. mdpi.com
10. F. Yang, H. Chen, Y. Shan, and L. Che, "Preventing postoperative moderate-and high-risk pressure injuries with artificial intelligence-powered smart decompression mattress on in middle-aged and elderly …," Journal of Hospital …, 2024. magonlinelibrary.com
11. M. A. T. Domingues, "Interoperable and Secure IoT Architecture for Digital Healthcare: Wireless Monitoring of Untethered Patients in Smart Beds," 2022. uc.pt
12. H. Dong and C. McGinley, "Design bugs out: a real world investigation of hospital bedside chairs and commodes," 2009. [PDF]
13. D. Mauricio, M. Gratacòs, and J. Franch-Nadal, "Diabetic microvascular disease in non-classical beds: the hidden impact beyond the retina, the kidney, and the peripheral nerves," Cardiovascular Diabetology, 2023. springer.com
14. M. He, B. Zhao, and J. Wang, "Particle pressures in gas-fluidized beds: A computational fluid dynamics–discrete element method study," Industrial & Engineering Chemistry, 2022. [HTML]
15. R. Veeraraghavan, "Wound closure and care in oral and maxillofacial surgery," Oral and Maxillofacial Surgery for the Clinician, 2021. springer.com