Exploring Relations Between Investor Goals and Exoskeleton Diversification

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

A human exoskeleton is any wearable structure or device that supports a person and their activities. Exoskeleton designs can take a variety of forms. Some are passive, while others have mechanical actuators. They might support different parts of the body or different kinds of movement depending on their intended usage. They have also been proposed for a plethora of applications, from medical rehabilitation to relief from fatigue and injury prevention for warehouse workers, to enhancing the strength of soldiers. The concept of human exoskeletons has been around since the 1960s. Since then, the idea of wearable technology assisting or enhancing human capabilities has remained prevalent in popular culture. Although research on wearable robotics also quietly continued during this time, it is only in recent years that the exoskeleton industry has begun to draw attention and significant investment. Developments in hardware are allowing exoskeletons to become lighter and more practical, while the integration of artificial intelligence is improving the interpretation of sensor data and supporting more stable movements (Bogue, 2022).

As research and development continue to enhance the capabilities of exoskeletons and their potential for widespread adoption, the exoskeleton industry has been experiencing rapid growth. The goal of my STS project is to identify key investors in this industry and how their contributions have helped shape it during this initial expansion phase. How is the global exoskeleton industry differentiated by the variance in investor goals? I hope this project will provide insight into the motivation behind design developments in different areas of the industry. This will contribute to the design considerations of my technical project by broadening my understanding of how our research will serve different groups.

I will approach this research project by first conducting a literature review to create an overview of the current state of exoskeleton research. This will include academic efforts before I narrow in to focus on private developers for my case study. I will perform more detailed research on three recent and contemporary leading companies in the American exoskeleton industry, Sarcos, Lockheed Martin, and Ekso Bionics. For each company I will study the exoskeletons they have produced and note key features in their designs. I will then identify major sources of external funding in its development and the industry it has been marketed towards.

In order to analyze the information I uncover, I will use the Tentative Periodic Table for Exoskeletons proposed by Weidner & Karafillidis to categorize the designs by the area of the body they target and the function they support. Organizing the designs in this way will assist in identifying trends in design capabilities and drawing conclusions about their goals. I also plan to apply concepts from the Social Construction of Technology (SCOT) approach described by Pinch and Bijker (1984) to my research in order to analyze the interactions between prevalent exoskeleton designs and the demands they seek to fulfill. SCOT maintains that to understand the success of a technology it is necessary to examine what relevant social groups play a role in defining the criteria for its success. A relevant social group is a group of people or an organization that attributes the same meaning to an artefact. The SCOT method describes the development of a technology as an alternation between variation and selection. Synthesizing my research in this way will allow me to identify where differentiation has been occurring in the exoskeleton industry. It will also enable me draw conclusions about the relationships between investors, companies, and the technical designs produced. To conclude my analysis, I will explore how specific design decisions were informed by investor demands and how this has changed during this recent period of exoskeleton industry expansion.

Literature

Those in the industry are familiar with descriptions of differentiation at a broad level. In order to facilitate discussion within the industry terms to categorize artifacts are a necessity. The common categorization framework that has been adopted is based largely on a proposal presented by Tim Swift in 2015. Swift identified four addressable markets for exoskeleton developers: military, industrial, consumer, and medical (Marinov, 2015). At the time the most companies were focused on medical applications, followed by military and industrial and finally a small number of consumer centered groups. Today industrial companies are in the spotlight, closely followed by medical. The number of consumer-focused companies still trails behind and consists mainly of small companies. This is most likely due to the continued cost barriers preventing companies from targeting a large consumer market.

Swift also expressed concerns about the stagnation of the exoskeleton industry, citing these cost barriers and the limitations of technology. In spite of these obstacles, industry growth has been steady (disregarding market disruption due to the covid 19 pandemic). Prevalence has become significant enough that concerns have been raised about the lack of oversight and studies on the potential drawbacks and safety concerns regarding these machines. For example, Howard et al. suggested that support exoskeletons for workers might actually expose them to a higher degree of risk because of the limitations they place on mobility (2020). These concerns highlight the continuation of insufficient user accessibility.

That is not to say that exoskeleton technology has not seen any development. In the past few years, a number of universities around the world have been using AI to improve EMG interpretation, gait training, energy efficiency, and other functions of medical exoskeletons. Bioservo, an exoskeleton company working in conjunction with some academic institutes, also used machine learning in conjunction with artificial tendons. Tendo, which similarly has ties to European academics, has similarly advanced soft robotics for medical use. Top company Wandercraft has been making strides in mobility assistance by introducing a self balancing design. Ekso, another big name in medical and industrial support, has supplemented their own designs with “gaitcoach” an application that processes data collected while using the exoskeleton and makes it accessible to physical therapists. Sarcos, which targets the industrial and defense markets launched the GuardianXO, a full body exoskeleton for industrial use that features 24 degrees of freedom.

Ekso and Sarcos are not the only big-name manufacturers to span multiple industries. Ottobock, which is known primarily for its medical products, purchased SuitX in 2021. A product of UC Berkeley, SuitX focuses primarily on support for the workforce. Another interesting example of this is Lockheed Martin. Lockheed is known for providing a number of services for the defense industry, primarily in the aerospace sector, but it is also one of the largest producers of exoskeletons. One of its main designs, ONYX, was developed specifically for defense applications. Another device, Fortis, helps Lockheed's workers with lifting heavy tools and is described as an industrial device. However, it should be noted that Fortis also has its roots in designs for defense applications.

Looking at this range of innovations, we see very little progress in consumer applications, strong industrial and defense applications, and continued prevalence of medical applications. Companies with roots in academia were moderately split between medical and other applications, and academic research was dominated by the medical field. A potential explanation for this is an increase in demand for assistive robotics in healthcare. Countries where academia lead breakthroughs in exoskeleton research, including the US, Canda, Sweden, and Japan, are also known to have old-age dependency ratio over 25%. Increase in population age has been a global trend and is predicted to continue in future years. This increase in the elderly population may be causing a demand for mobility assistance technology. The United States has also seen an increase in musculoskeletal disease in the past decade. This may explain an increase in investment in rehabilitation technology, as well as industrial support which may have the potential to prevent some of these conditions.

Case Discussion

To better understand how these designs were influenced by investors, I took a closer look at the products of three American exoskeleton companies. I selected Sarcos, Lockheed Martin, and Ekso Bionics for this analysis. All of these companies are successful exoskeleton manufacturers and well known in the exoskeleton. Additionally, they have produced multiple designs across multiple industry targets.

The designs from Sarcos stayed the most consistent over time. Initially a part of Raytheon, Sarcos was responsible for producing the XOS and XOS2 in the early 2000s. These designs were developed at the request of DARPA, the Defense Advanced Research Projects Agency (Guizzo, 2011). The designs were based off the Wearable Energetically Autonomous Robot (WEAR) design developed by Sarcos as a proof of concept before it was acquired by Raytheon. This project was also funded by DARPA, which provided an investment of around fifteen million dollars.

Following its split from Raytheon, Sarcos took on more commercial investors, including GE, Microsoft, and Caterpillar. In 2016, these investors supported the beginning of development of the Guardian XO, alongside continued support from the US military. The Guardian XO is an updated full body design (Ackerman, 2019). In 2018 Sarcos formed the Exoskeleton Technical Advisory Group, or X-TAG, a group of representatives from companies interested in industrial exoskeletons. The group included executives from Bechtel, BMW, Caterpillar, Delta Air Lines, GE, Schlumberger, and Würth Industrie Service GmbH & Co. KG, among others, and aimed to improve the company's understanding of industrial support needs and parameters (Mack, 2018). Later in 2021, Sarcos began trading on the Nasdaq with a new board of directors featuring past and current leaders of Apple, The Boeing Company, Credit Suisse, Delta Air Lines, Microsoft, Nextel, and the U.S. Department of Defense.

Heavy investment from the DoD is a common theme for these companies, least surprisingly for Lockheed Martin, a prominent aerospace and defense company. Lockheed's first foray into exoskeleton development was the Human Universal Load Carrier, or HULC. The design was originally developed by Berkeley Bionics (which would later become Ekso Bionics) in 2008. Lockheed acquired the license for the design in 2009 and advanced and tested the design for military applications in the following years. The device consists of titanium "legs" that can support loads attached to a frame on the users back or front. This would allow soldiers to carry loads of up to 200lb but also aimed to reduce musculoskeletal injuries (HULC, 2020).

Applying the principles learned in pursuing those goals, Lockheed next developed the FORTIS exoskeleton. FORTIS is a passive system that transfers load from a "third arm" attachment to the ground through a series of joints along the user's lower body. The design was developed as part of the National Center for Manufacturing Sciences' CTMA program. The Commercial Technologies for Maintenance Activities program "is a Cooperative Agreement in partnership with the Office of the Deputy Assistant Secretary of Defense, Materiel Readiness (ODASD MR) and NCMS" (Commercial Technologies for Maintenance Activities, n.d.). It provides its commercial partners with support for R&D and commercialization. A FORTIS Knee-Stress Relief Device (K-SRD) was also developed to reduce fatigue when walking and climbing. The technology behind this design went on to power ONYX, Lockheed's most recent design. Following the design's release in 2018, Lockheed quickly received a $6.9 million award from the U.S. Army Natick Soldier Research, Development and Engineering Center (NSRDEC) to further develop the exoskeleton for use by soldiers (Lockheed Martin, 2018).

Ekso Bionics has experienced the highest degree of differentiation over time, both in terms of their physical designs and design goals. The company started out as Berkely Bionics, working off of a licensing agreement with the University of California to develop the exoskeleton technologies explored in its labs. It was during this phase that it introduced the HULC design that would be developed by Lockheed Martin (Upbin, 2014). Subsequently, Berkeley Bionics built off the HULC's legacy to create the eLEGS. This device provides support to the lower body to allow those suffering from paralysis or other lower limb impairments to walk again (Ackerman, 2010).

In 2013, Ekso started work on the Ekso GT robotic exoskeleton, another lower body design to support walking rehabilitation, and in 2014 they received a grant from the National Institutes of Health (NIH) to develop a pediatric version of the exoskeleton (Ekso Bionics Holdings, Inc, 2014). In 2016, the device was approved by the FDA for use with stroke and spinal cord injury patients (EKSO, 2016). During that same time, Ekso was also subcontracted by Boston Dynamics to produce a project for DARPA's Warrior Web program. The project advanced a design of motorized leg braces intended to allow soldiers to "walk, run or climb farther and faster without extra effort" (Upbin, 2014).

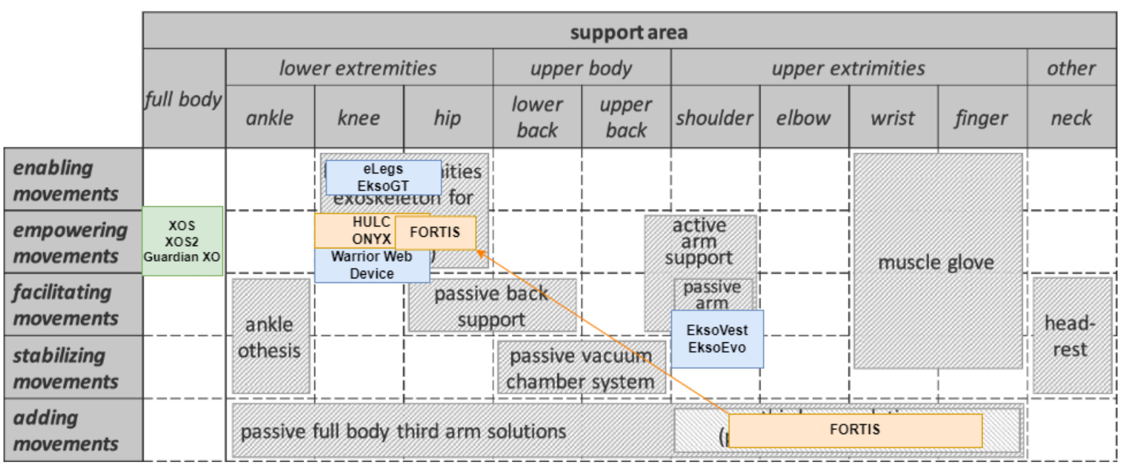
Ekso also began branching into industrial markets. The EksoVest, a passive upper body model, supports the user's arms and shoulders. The device was developed in partnership with Ford with the aim of reducing injuries and fatigue in factory workers (Chow, 2017). The following Ekso EVO built off of the EksoVest to further this mission while providing increased comfort and mobility to the wearer (EKSO, 2020).

Analysis

To instruct my analysis I used the classification framework proposed by Weidner & Karafillidis to plot the models from the case companies on their "Tentative Periodic Table for Exoskeletons."

Figure 1

Tabular Arrangement of Exoskeletons by Design Characteristics



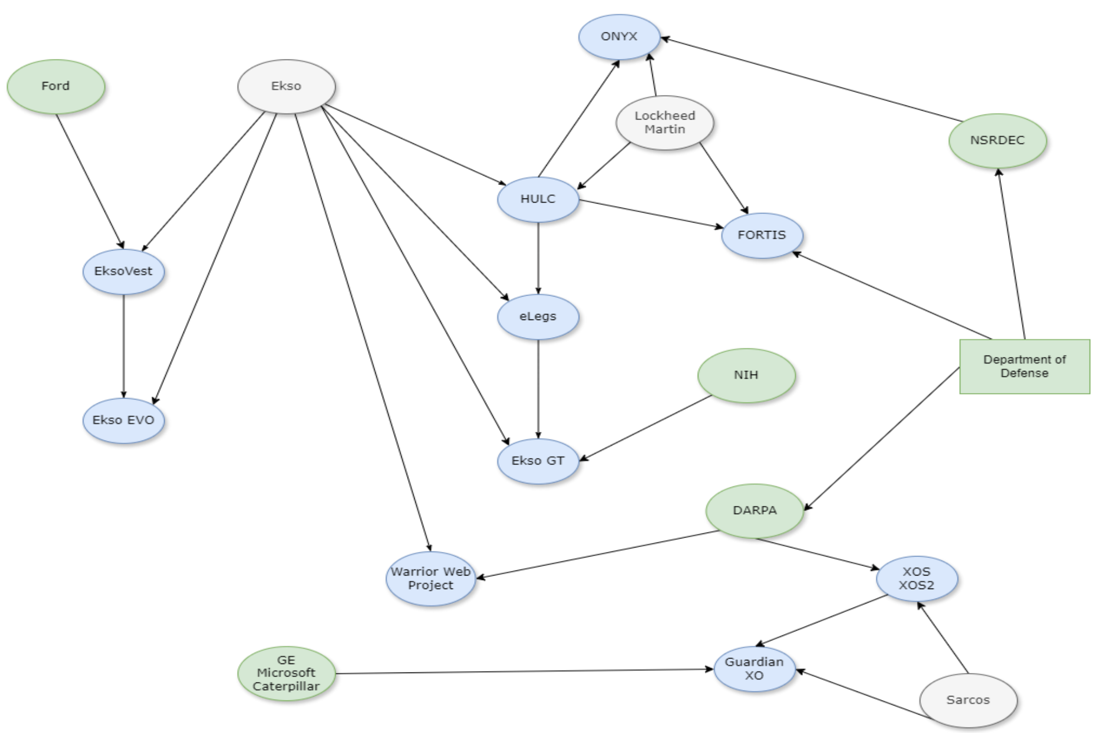
This framework categorizes exoskeletons by the movements they are associated with and cross indexes them by the area of the body the support is provided to. Five categories of motion are used. Enabling movements refers to supporting a motion that can not be performed independently, for instance support for paralysis. Empowering movements allows a user to perform regular movements to a significantly greater degree, while systems that facilitate movements improve ergonomic conditions to reduce stress on the user without enhancing motions. Stabilizing movements supports maintaining a position and adding movements allows movements extraneous to the human body (Weidner & Karafillidis, 2018).

It is apparent that the designs are concentrated around support for the lower extremities, specifically to enable or empower and facilitate the wearer's movements. Devices like the EksoVest and Ekso EVO are classified as facilitating and stabilizing movements because they reduce the risk of overload when the target movements are performed and allow workers to maintain strenuous positions. This aligns with Ford's involvement in the EksoVest's design. Ford uses overhead assembly lines and claims workers on these lines lift their arms an average of 4,600 times each day. This repeated motion and need to hold their arms above their heads created a strain on the workers the EksoVest aims to eliminate (Chow, 2017). While also targeted towards industrial applications, FORTIS relies on lower body support and crosses into the adding movements category because of its holding arm extension.

There is an apparent correlation between the development of lower limb exoskeletons and the involvement of defense investment. Almost all devices belonging to that category were developed specifically for military use or built off of designs that were, as can be seen in the web below.

Figure 2

Map of Exoskeletons, Companies, and Investors



Additionally, all of the devices developed for defense applications were categorized as support for lower extremities or the full body. This makes sense given the defense department's goal to support the activities of warfighters by enhancing their capabilities. While defense missions serve a variety of goals in many different environments, enhanced mobility of soldiers and equipment is widely applicable. Since these activities often require incredible endurance, it makes sense to pursue technology that can remove loading from the soldiers and assist common movements. This is best accomplished through designs targeting adaptive support for the lower body.

Since companies develop expertise in lower limb products by completing these projects, it makes sense that a number of their subsequent projects would make use of this knowledge. However, as investments from the industrial and medical industries become more prevalent, products may begin to reflect a shift in design priorities. While patients and industrial workers also have varied needs, they are more likely to desire support for a repeated motion in a stable environment than warfighters. This may cause more variance in the areas of the body designs target while more emphasis is put on the enabling and facilitating movement categories. The exoskeleton market will likely experience a greater degree of differentiation as more research is performed to develop this technology for more distinct groups.

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