A Sociotechnical Analysis of the Development of Light Technology

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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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The use of technology as a means harness and emit light has been an integral part of society for hundreds of years. As technological capabilities have advanced, the form of these technologies has evolved as well. From fire and torches, to kerosene lamps, to Edison bulbs, to fluorescent and LED technologies and the like, humans are constantly reworking our understanding of the best ways to harness light. However, as with any technology, the factors that drive its development are more nuanced than immediately apparent. In order to accurately assess the current climate of sociotechnical factors driving forward light technology, we need to understand how the form of light technologies have evolved in response to past social influences. Understanding the parameters that have guided the technologies' development, as well as the technical development itself, will allow us to properly analyze the current factors that influence the development of light technology as well as make a broader prediction about where light technologies are aimed in the future.

Scholars have developed several methods to describe and analyze the reciprocal relationships between science, technology and society. These methods, called STS frameworks, can be used to outline the role that science and technology have on society, and in turn the role that society plays on science and technology. The Social Construction of Technology (SCOT) is a useful STS framework that can be used to help analyze the connection between the development of light as a technology and the development of its perception in society. This framework posits that successful innovation, as well as unsuccessful innovation, is a product of its social context. That is, one cannot assume that a prevalent technology is successful simply because it "works" better than its current competitors or those that have come before it. Rather, it is up to the analyst to evaluate the social context that promotes (or demotes) the technology.

SCOT also introduces the concept of relevant social groups. These relevant social groups are effectively the groups that compete to control a design. SCOT posits that each group's specific motivations for creating the technology will establish a distinction in the way they design the technology. This framework will allow examination of the innovative breakthroughs in light technology through the lens of the social contexts and the groups that created them.

Background

Over 150 years ago, inventors began to work on the lighting technology that would go on to redefine day-to-day functionality forever. This technology eventually "changed the way we design buildings, increased the length of the average workday and jumpstarted new businesses. It also led to new energy breakthroughs -- from power plants and electric transmission lines to home appliances and electric motors." (Matulka & Wood, 2013). In the late 1800s, scientists such as Thomas Edison, William Sawyer, and Albon Man worked to create incandescent lamps that functioned by producing light when a filament is heated with electrical current.

It is important to note that Edison's involvement in electric lighting was not limited to the improvement of bulbs. Edison also sparked the movement toward making electric lights practical. Namely, Edison developed Pearl Street Station in 1882, the first complete system for commercial electricity and power. This station, in Lower Manhattan, was powered by a series of early generators that allowed the plant to service a square mile of the city with electric light. In order to distribute this power, he developed a series of underground tubes and wires spanning approximately 100,000 feet in length (Pearl Street Station, 2017). For reference, high-voltage transmission lines spanned more than 60,000 circuit miles by the late 1960s (Power Grid History, n.d.). Moreover, Edison was tasked with creating a system to measure the amount of power his customers used, and consequentially developed the first electric meter – a way to measure current flow over time. It was this type of forward thinking that set the framework for the creation of the power grid we know today.

However, the innovation did not stop with Edison. In the 19th century, discharge lamps were introduced when Heinrich Geissler and Julius Plücker were able to produce light by passing electrical current through a tube with gas at a low pressure (The Editors of Encyclopedia Britannica, 2016). This served as a basis for many of today's common light technologies, such as neon lights and low-pressure sodium lamps (Matulka & Wood, 2013). These lightbulbs displayed a significant increase in efficiency, but were still impractical to for residential use due to the limits on hues that the gases would glow. By 1951, the use of fluorescent lamps had surpassed that of incandescent in the United States, due to the development of phosphors and the need for energy efficient lighting in American war plants. (Smithsonian Institution, 2012).

It wasn't until the energy crises of 1973-74 that manufacturers started to develop compact fluorescent bulbs (CFLs) compatible with residential use. The Organization of Petroleum Exporting Countries (OPEC) placed an embargo on the amount of oil sold to the United States, causing prices to skyrocket. Although the embargo was lifted in 1974, prices stayed high, eventually leading to the creation of the Department of Energy as well as the passing of the Energy Policy and Conservation Act (Donoff, 2016). Challenges with the feasibility and expense of mass production kept CFLs off the market until the mid-1980s, when these bulbs became available for about $25-35. In contrast, today's CFL bulbs can cost as little as $1.71 per bulb (Bermudez). Manufacturing constraints kept the bulbs big and bulky, creating issues with fitting into light fixtures. Many consumers cited this, along with price and inconsistency, as reason for not wanting to make the switch from incandescent lighting. By the 1990s, these bulbs had become over 75% more efficient than incandescent bulbs and were able to last 10 times longer, making them extremely viable (Matulka & Wood, 2013).

Today, light-emitting diodes (LEDs) have made their way to the forefront of light technology. LEDs use a semiconductor to convert electricity to light and create light in a specific direction. This is different than incandescent bulbs and CFLs, which often require reflectors and diffusers (Matulka & Wood, 2013). First established in the 1960s, LEDs were primarily used as indicator lights in electrical equipment. However, rapid increases in energy efficiency, brightness, and lifespan compared to CFLs and incandescent bulbs allowed these bulbs to transition into residential, commercial, and industrial applications. The LED also offers an advantage over CFLs in that it doesn't have a "warm-up" time. LED bulbs can be thought of as "instant-on", while CFL users must wait for the current to heat up cathodes that in turn heat up the gas that will emit light. Some users also complain about using CFLs in outdoor applications under colder temperatures, where the gas is unable to heat up to its full capacity (Kiger, 2018).

It is clear that technological progression has significantly influenced the development of light technology for over a century. Today, it is nearly impossible to imagine a world without transportation at night, working after dark, or even enjoying night-time entertainment outings such as concerts and sporting events. None of these things would be possible if it weren't for the advancement of light technology allowing people to function properly even when the sun does not provide adequate light. With each advancement, there is a clear motivation for the push from one form of the technology to the next, and this advancement is ongoing. By studying these motivations and analyzing them with the help of STS frameworks, it may be possible to determine what areas of the world new light technologies will illuminate next.

The Need for Development Drives The Technology Forward

It is nearly impossible to imagine a world where humans could not summon light with the push of a button. In fact, with the rise of voice assistants such as Amazon's Alexa or the Google Assistant, even pushing a button is becoming yesterday's technology. Ultimately, this light provides a freedom that would have been a pipe-dream just a few hundred years ago. Before the invention of gas lights, all light had to be constantly monitored to supervise the open flames. Often, the only things that could be used as fuel for lights produced smoke and odors. To this end, it was often required that people put out their cooking fires immediately after dinner. In fact, the word "curfew" even comes from an old French word – couvre-feu – meaning "cover fire". (Brox, 2011). Today, curfew is commonly associated with the end of the night. And back then, this would have been quite literal. There was no public infrastructure, such as street lights or office buildings, that would have kept the streets lit up even after home fires were extinguished.

However, as areas became more populated, a need for light in public areas surfaced. Eventually, light seeped from purely residential uses in the form of street lights, paid for by taxpayer dollars and managed by lamplighters. This made it possible – for the first time ever – to travel effectively after dark (Brox, 2011). Fast forward just a couple hundred years, and the availability of light has completely reshaped the practicality of industrial and recreational activity after the sun goes down. Very quickly, industrialists realized that an increase in workable hours in a day would lead to increased profits. As a result, factories, rail yards, docks, and quarries became workable well into the night. Those who weren't working after dark were afforded the opportunity to participate or spectate in various recreational activities, such as sports (Brox, 2011). Here, it is evident that the association of light technology with increased productivity and possibility influenced its social context positively, demonstrated by the spread of the technology into multiple sectors.

The development of light technology has also driven safety and efficiency in these practices. Take, for example, the use of services like FedEx or Amazon Prime. Their overnight delivery systems would not function properly without night-capable airports or headlights on cars (Smithsonian Institution, 2012). It is also clear that the development of reliable headlights, as well as properly lit road-signs, and exterior lighting has increased the safety and efficiency of these delivery systems. By applying the SCOT framework, the developments in light technology become more understandable. For example, consider two human desires that can be thought of as universal – the desires for safety and social interaction. Most people today would agree that walking in a well-lit area makes them feel safer than walking in a dark area. Social interactions almost always occur in the presence of some amount of light, even after the sun has gone down. It is clear that the development of light technology creates opportunities for both of those desires to be fulfilled.

Social Perception Can Influence the Acceptance of the Technology

We can also use SCOT to explore Thomas Edison's rise to prominence through the invention of the lightbulb. Edison is widely regarded as the great inventor of the lightbulb and the father of modern electricity. Ernest Freeberg, however, in his book "The Age of Edison: Electric Light and the Invention of Modern America", suggests that the light bulb is a reflection of many ideas from many inventors. In fact, Freeberg suggests that what made Edison successful wasn't his lone genius at all, but rather his understanding of the complex social process that is invention. His assembly of a research and development team was what eventually led to the production of the lightbulb (Berger, 2013). Freeberg goes on to say that Edison is typically credited as the inventor of the lightbulb for several reasons. Namely, Edison was a "great promoter of his image, and it was important to claim to be the sole inventor in order to win the crucial patents that would determine which person got to control the market share" (Berger, 2013).

Edison understood the relationship between societal perception of himself and his technology, and the technological product that he was working on. It is that relationship that is the essence of SCOT. The social climate during Edison's time was one where people "wanted to believe in the idea of an inventive genius," and Edison met that demand (Berger, 2013). In contrast, examine the relationship between Edison and his counterpart Nikola Tesla. Regardless of the fact that Tesla is credited with the development many crucial technologies, such as x-rays, radio, and early electric motors, Edison has become far more popular. One article cites that the reason for this discrepancy is due to Edison's ability to turn his inventions into commercial successes, whereas Tesla was often unable to do so (Diallo, 2015). Edison understood the way to acquire social promotion of his ideas, leading to patents, recognition, and market share, while Tesla's ideas were often left to be commercialized by others. Edison's realization that his ideas needed to deliver commercial success, in a way that rewarded him with more funding and the ability to keep creating, is what eventually made him a singular identity at the forefront of American inventors.

Another relevant example of the effect of social perception on the acceptance of technology can be found in the case of the implementation of LED and CFL bulbs into residential applications. In 2014, National Geographic released an article discussing five common beliefs about these newer bulbs that prevent consumers from implementing them in their homes (Kiger, 2018). By considering several of these concerns via SCOT, it is possible to understand the beliefs that surround LEDs and CFLs. In this instance, there are several relevant social groups that influence the change in the home from incandescent bulbs to their more efficient counterparts. First, consider the homeowners, who state concerns of the newer CFL bulbs not being supported by the lighting infrastructure they currently have in their homes. Thus, the cost for switching from incandescent to CFL bulbs is far broader than just switching bulbs, but involves purchasing new light fixtures, or saying goodbye to dimmer switches. Even though many CFLs now work with dimmer switches, many homeowners still believe this is not the case. Asking homeowners to change when it will save them money is one thing, but asking them to change when they it costing them something is a different ask altogether. Here, it is clear that the social context surrounding these CFLs demotes the technology's success, forcing inventors and manufacturers to continue to develop the bulbs to meet the needs of the consumer.

One must also consider the initial perception that consumers envelope with CFL or LED bulbs. The initial costs of CFL or LED bulbs are several times more expensive than incandescent bulbs (Kiger, 2018). Moreover, there is a large gap in understanding for some consumers with regards to the safety of CFLs, who fear that mercury content and ultraviolet radiation leakage could cause safety concerns in their homes. While these concerns are not without basis, the facts state that after breaking, it "would take weeks for the amount of mercury vapor in the room to reach levels that would be hazardous to a child" and that UV radiation is completely avoidable by protecting lightbulbs with fixtures and remaining a reasonable distance away (Kiger, 2018). Still, apprehension from homeowners establishes a barrier that is large enough to steer some of them away from switching. On paper, it is clear that CFL and LED bulbs are an upgrade from incandescent bulbs. Their superior efficiency and longer burn time save money in the long run, despite steeper initial costs. Thus, the reason that some consumers choose not to switch must be due to other factors. By examining these factors through the lens of SCOT, the influence of societal perception on the success of CFL and LED bulbs becomes more clear.

Social Context Can Drive The Development of the Technology

In recent years, the social climate has become the primary driver for the development of light technology. A push for energy efficiency has made its way into public policy, raising the standards on what type of lightbulb is permissible in the home. In 2007, President George W. Bush signed the Energy Independence and Security Act (EISA), targeting energy-inefficient lighting as a means to help the country become energy independent (EPA, 2020). There were also several other provisions in the bill that did not relate to light efficiency, including higher MPG in automobiles, training for green jobs, and increased reliance on biofuels (EPA, 2020). The EISA clearly does not ban the sale of a specific lamp type, but rather raises the efficiency standard by requiring at least 27% less energy consumption in bulbs that traditionally use 40-100 watts of electricity by 2014 (Action Services Group, 2019). Additionally, a second part of the law would have placed a base efficacy for bulbs at approximately 45 lumens per watt, 60-70% more efficient than the current standard for incandescent bulbs (US EPA Backgrounder, 2011). This portion of the law, set to start in January 2020, would have made current incandescent bulbs illegal. These regulations would eliminate the need for approximately 25 large power plants nationwide, or about the amount of power needed to power all the homes in Pennsylvania and New Jersey. However, the Trump administration eliminated these pending requirements in September of 2019. California is abiding by these new standards, due to a secondary regulation put in place in 2018 (Action Services Group, 2019).

These regulations are just part of the network that influences the use of light technology. In contrast to Edison’s time, the desire to change the technology is indirectly related to the form of the technology itself. Whereas Edison and his counterparts strived to create a new, novel form for harnessing light, today's developers must change the technology to keep up with changing regulations. SCOT provides clarity on this topic by demonstrating that the social climate – the goal for energy efficiency and independence – has driven policy makers. These policy makers act by making regulations to help point society in the direction of that goal. These regulations create a need for new technologies that otherwise would not be needed. The ability of this societal goal to influence the design of light technology aligns with a clear tenet of SCOT: that relevant social groups will inherently create distinctions in design.

Moving Forward With Light Technology

So far, the goal of this paper has been to understand the technical and social motivators that have driven light technology to this point. Now, the hope is to examine the current motivations surrounding light technology in an attempt to understand how design decisions will be made in the future. Currently, approximately 940 million people (about 13% of the total world population) do not have access to electricity (Ritchie & Roser, 2019). While this percentage is decreasing, this is still a significant amount of people that don't have the ability to have light after dark, safe cooking facilities, and many more utilities that citizens of developed countries have become accustomed to. In places like the Navajo Nation, homes are so spread out that it can cost as much as $40,000 to connect each home to the power grid (Morales, 2019). In other countries, where power grids are nonexistent or even farther away, the costs could be worse. This provides a motivation for the development of technology that pushes away from a centralized power grid. Decentralized power, such as solar power, has opened the door for more of the population without access to traditional power grids to have electricity. As of 2017, there were approximately 1.3 million solar installations in the United States (Ritchie & Roser, 2019).

In order for decentralized power supplies to be effective, however, the need for increased efficiency in lighting technology is still eminent. This case is a clear demonstration of the theories presented in SCOT. In order to disconnect from central power, lighting efficiency will become the focal design concentration in order to propagate the ability for decentralized power. However, once this design distinction is established, it could be useful in all areas, not just areas that strive for decentralized power.

The introduction of smart technology has significantly aided the battle in efficiency, primarily through the realm of accessibility. Lights are no longer bound by the words “on” and “off”. Newer LEDs introduce the ability for lights to change color and intensity. Remote control lights work via Bluetooth and WiFi, and the integration of voice assistants make these changes even more accessible (Kopko, 2018). Occupancy sensing capabilities such as motion and heat sensors provide another upgrade to light systems (Tolfo, n.d.). By dimming and turning off lights automatically when spaces are not being used, the amount of energy used is significantly decreased. Companies like Acuity Brands take this a step further by integrating infrastructure with the capability to link with mobile phones, allowing insight into human traffic patterns. As a result, spaces with less traffic may function with dim light or no light at all when possible (Kopko, 2018). This is also a practical solution to the issue of light pollution, which has risen in popularity in recent years. Today, studies are shifting toward how a lightbulb’s brightness, color, and usage time impact the ecosystems around it with unwanted glare, sky glow, and reflected light (Tafreshi and Talwar, 2019).

Light technology also has the ability to influence connectivity. Enter LiFi, a light-based wireless networking technology that uses LEDs to transmit data. In addition to a speed increase from traditional WiFi technology, LiFi also makes data transmission possible in areas where electromagnetic interference is problematic, as well as increases bandwidth capabilities (What is LiFi?, n.d.). LiFi establishes a framework for the cities of the future. The ability to share information over LiFi introduces the capability for macro-scale connectivity in infrastructure, in the form of things like traffic-sensitive street lighting. Eventually, the hope is that these street lights can "ultimately form a neural network that runs and manages cities. That network then becomes a massive system optimizing traffic and transport systems and monitoring public safety" (Kopko, 2018).

One of the most welcome aspects of light is the safety and certainty it provides. But, like any smart technology, smart lights open the door for susceptibility to hacking and other security risks in the home. As lights become a more connected part of the home, it is possible for others to gain information by using lights as a way to take over networks (Cuthbertson, 2020). This poses a very real drawback to smart lighting systems. If people feel as though their security is threatened by these systems, it would almost certainly reduce their willingness to bring those systems into their homes and workplaces. Thus, as the technology advances, it will be up to the consumers whether or not they feel like the technology adequately mitigates their concerns for security. Since the technological capability of this technology is not its downfall, it is surely the social perception of the technology that will determine its success.

Conclusions

The landscape of light technology has continuously changed over the past several hundred years. Behind each technological advancement, there has been a sophisticated system of social motivations that influence not only the design of the technology, but the way it is perceived by society. From the need for a safe and reliable light source, to the integration of a power grid and the push for increased efficiency, to the push for decentralized power and the desire to mitigate light pollution, it is clear that those social motivations have ebbed and flowed over time. With the help of SCOT, it becomes possible to understand the complex relationships between the different social groups that influence development decisions of light technology. Ultimately, this framework has illuminated the fact that light is a social technology. It provides humans with safety, the ability to travel, work, and socialize in a variety of different settings. As it has developed, light has served as a conduit for other technologies to thrive by helping to opportunities for social collaboration. For this reason, it is evident that the development of light technologies will continue to advance, guided by the parameters set by the social context at the time.

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