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Architectural Design Innovation as a Contributive Factor for the Success of Battery Electric Vehicles in Automobile Industry

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Abstract

This essay proposes how architectural design innovation relates to the development of incremental innovation triggered by new technology, building upon the architecture, but continuously reshaping to meet new requirements by defining new sets of functions or forms. Besides, analysis is centralized around the theoretical application of architectural design innovation for live systems such as automobiles, which are continuously adapting to new sets of requirements. To elaborate the practice of this application, a case study of Tesla BEVs is provided to offer unprecedented attributes for an automobile. Furthermore, methodologies on executing architectural design innovation have been established on in this essay, which as well examines the contributions of it in the product dimension, not only helping reconfiguring selected elements of the architecture, but enabling completely redesigning it to clearly deliver value along the system and where the behavior of the system could be traced back to the needs of the stakeholders.

Keywords: Architectural; design innovation; battery; electric vehicle; automobile; Tesla.

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1. Introduction

When a new technology appears in the ecosystem, the evolution of the new-technology's architecture is originated; from that initial set of time, in a way that is reminiscent of the early stage, continuing until the architecture gets established.

Even since General Motors (GM) established the strategy called a car for every purse and purpose, which fundamentally segmented the U.S. automobile market by price range, the industry has witnessed the proliferation of multiple sub-brands from the majority of the major auto OEMs (Original Equipment Manufacturers), as well as emerging small spin-offs and start-ups, attempting to address each segment with at least one competitive product. As result of this type of sustaining - and strategic - innovation following the raise of the ICE as dominant design, the industry ecosystem today is fragmented with multiple segments having blurred delimitations. In addition to this market fragmentation, the idea of developing alternative fuels has seen its strongest proliferation in recent years; from the launch of the first plug-in hybrid (PHEV) by Toyota Motors in 1997, to the foundation of Tesla in 2003 [1].

The concept of dominant design and innovation dynamics model set the foundation to analyze the current stage of the automotive industry evolution characterized for undergoing a period of clear uncertainty.

Although the future is unclear we can, however, break down this transformation by calling out two core forces thrusting the shift to a new transportation ecosystem: 1) Strict regulations to mitigate global C02 emissions in response to global warming have put substantial pressure on automotive OEMs to rethink the concepts of the ICE powered automobile and fuel efficiency. 2) Technological innovations that: a. Enrich the user experience through state of the art user interfaces, in-vehicle connectivity and autonomous-driving capabilities. b. Create new business models for human transportation and mobility, disrupting the traditional schemes of ownership and usage of the automobile [2].

Expanding on the Innovation Dynamics model applied to the current landscape suggests that the industry, and more specifically, the dominance of the ICE as the undisputed technology to power automobiles, is going through dynamics that are similar to those that appeared more than 100 years ago, before the ICE established itself as the dominant design forcing an extensive number of firms to exit the market. Therefore, the theory implies that at some point another dominant design will emerge and the automotive industry will change dramatically; established companies are unlikely to transition successfully, given the challenges of adopting a completely new architecture, and new companies, even outsiders, will have greater survival odds. As a matter of fact, such technical uncertainty will result in a diversity of product designs [3].

Taking a retrospective look at the most recent and considerably impactful attempt from a firm to develop an alternative power technology and vehicle architecture, the launch of the Toyota Prius in 1997, it is clear that there are in fact multiple technologies emerging in the spectrum competing to win the race to dominate the market. While the architecture of a PHEV has not entirely removed the need for an ICE, it has certainly created and leveraged parallel interfaces amongst conventional elements of form within the architecture.

2. Background

2.1 The concept of BEV (Battery Electric Vehicle)

A BEV (conventionally known as EV) is a vehicle that uses a battery to store the electric energy, that powers an electric motor or motors, and that requires to be charged by a power source. Up to this day, plugging the vehicle to the electricity grid is the most common way for recharging EVs; however, there are multiple developments focused on "wireless" (non-plugged) alternatives that could potentially contribute in boosting the adoption of EVs.11 As for EVs storage technology, the lithium-ion battery, commonly used on consumer electronics, has established its dominance as a mature technology with wide market acceptance amongst consumers over alternative technologies such as nickel-metal hydride batteries, more commonly used on hybrid vehicles and medical equipment.

Since the market introduction of the Nissan Leaf in 2010, BEVs have won territory against other EV/HEV architectures like the hydrogen fuel-cell EV.12 The case of the hydrogen fuel cell has been addressed in multiple studies, even concluding that a dominant "prototyping" design has emerged. However, there has not been enough performance data that could indeed establish its dominance in the EV ecosystem and only a minimal number of firms have attempted and continue to develop technology that could overcome some of the challenges of this technology; being distribution, storage and overall handling of hydrogen, one of the key ones. In addition to the high cost of hydrogen as fuel and the required investment in infrastructure, the resultant efficiency of the electrolysis process to convert electricity into hydrogen is approximated at 75%, while the efficiency of the energy cycle of the Lithium-ion battery is 86% approximately [4].

Despite the superior efficiency of BEVs over hydrogen FCEVs and the fact that the latter have not been mass-produced, BEVs have proven superior performance in several other attributes even when compared against gasoline-powered ICE vehicles [5]. In addition to that, the architecture of the BEV benefits from less number of elements of form and therefore, less number of relationship that have to be managed, since all the system functions exist within the product architecture.

Going back to the theory of innovation dynamics, it has been shown that in many proven cases innovations that substitute established products tend to appear within the industry; but, in contrast, there is also a strong correlation between innovations that are developed by new entrants from a totally different industry in the creation of new market niches, which tends to encourage the entry of many players. Utter back proposed in 2004 that the new technology has to be evaluated against the same performance parameters as the incumbent technology that is, " If the innovation has real merit, it enters a period of rapid improvement to match the performance of the established technology, eventually, surpassing it (Utter back 2004) [6]. In the following sections, the performance of BEV’s over ICE vehicles will be analyzed against several attributes; the results make it mandatory to clarify that since the appearance of the first EV produced by General Motors, the EV1, the overall performance of EVs is far superior than competitors in the same market segment, even grasping into segments traditionally occupied by "high-performance " automobiles.

To further elaborate on the hypothesis that BEVs are setting the precedent to emerge as the next iteration of a dominant design for the automobile architecture, in October 2014 the International Energy Agency (IEA)13 released the report EV City Casebook: 50 Big Ideas Shaping the Future of Electric Mobility which portraits a series of potentially big ideas that could increase the adoption of EVs globally. Using Gartner 's Hype Cycle14 methodology to analyze the outlook of EVs within the technology space, the document states that technologies go through different phases over different periods of time (years) and each one with different characteristics; the time between each of the phases varies from technology to technology, affected by several factors throughout the course, and has a direct impact on the expectations of a certain technology [7].

3. Case studies

3.1 Tesla's projected innovation trajectory

Tesla's BEV architecture stays as an architectural innovation, building knowledge from the interactions within the system; but new BEV architectures emerge and become superior for the particular attributes already set by the current architecture

To support the hypothesis where Tesla's BEV architecture gets accepted by customers, an argument can be made where Tesla has already partnered with incumbent automakers to supply components from its architecture;17 however, a critical aspect to consider is whether or not the incumbents obtaining these components - or entire subsystems - are able to adapt their vehicle architectures to successfully introduce them into their vehicles. Let us remember that architectural knowledge plays a fundamental role in moving up the ladder should the new comer's innovation become established as the standard; therefore, while such incumbents will for sure may have a huge advantage when it comes to some component knowledge which remains relevant, the architectural knowledge that understands the interrelation of components and anticipated behavior, stays with whoever developed the architecture. Tesla will not lose that advantage in the near future [8].

Tesla's annual report 2014: "Beginning in 2008, we commenced efforts on a powertrain development arrangement with Daimler. Since that time, we have developed and produced powertrain components for Daimler for the Smart for two electric drive program, the A-Class electric vehicle program and the 8-Class electric vehicle program. We started to supply production parts for the 8-Class electric vehicle program in 2014 and expect to continue to supply parts under this program for the next few years [6]. We provided development services to Daimler and Toyota to assist in the development of electric powertrains for the Mercedes Benz 8-Class EV and the Toyota RA V4'.

3.2 Evolution of autonomous capabilities within the Autopilot architecture

Opportunities exist in leveraging incremental innovations from traditional automotive supplier practices, processes and component knowledge. If Tesla's BEV architecture consolidates as industry's future dominant design, then all the architectural knowledge acquired will become competitive advantage over competitors, potentially representing a business opportunity to sell technology and/or "sell" architectural knowledge. Incremental innovation will emerge from each subsystem within the architecture as new technology gets developed and implemented, from the component level and up to the system level [9].

New infotainment technology with improved connectivity and potential inclusion of mobility services improvements in powertrain performance driven by optimization of components. Since Tesla has designed an architecture where the interfaces between elements of form are well-defined, further improvements in such elements will translate into modular innovation; that is, the linkages between components will remain practically the same, but the components will be changed. This type of improvement represents an ideal opportunity because if the end product could be improved by replacing entire mod u les, while keeping the boundaries of such modules, then customers will benefit from getting a new and better product, without having to wait for the next model yea r and buy an entire new vehicle. Furthermore, there is a potential revenue stream from mod u lar innovation, while execution is relatively easier than redesigning the entire vehicle, but more substantial than just optimizing a few components with relatively low impact to the system behavior.

4. Methodology of Architectural design innovation

In order to understand the reach of the dominant design concept within the innovation scenario, it is important to unfold all the dimensions where such dominance is embedded: from the founding technology or initial technological development that triggered the innovation trajectory, to the specifications and requirements of regulatory, legal or market nature; and last, but not least, the user and market criteria about performance attributes. Consequently, a dominant design is embedded in the product's architecture: from the elements of form, from where the product can be decomposed, to the intricate functionality of such elements of form that give the product its anticipated and emergent behaviors

A dominant design outperforms any other competitor when compared against performance of one or multiple attributes and market criteria; while at least a handful of contributing factors in different dimensions eventually lead to market dominance, a technology that offers a superior performance in most of those dimensions labeled as "most important" by the end user, increase the probability of achieving such dominance (Suarez 2004). Evolving from the original conception of dominant design from Abernathy and Utterback back in 1978 as "an architecture that establishes superiority and results in market adoption", it can be inferred that EVs fall in the category of architectural innovation [10].

4.1 Concurrent engineering for incremental innovation

The traditional approach of automotive ICE OEMs has been the application of concurrent engineering to optimize standalone components and assume that, by optimizing each of these components, the end product - the sum of all the components - will be optimized. However, throughout the years, automobiles have become more complex, adding a sizable amount of components and functionality; thus multiplying the number of interconnections between such components. Concurrent engineering has been the pillar of incremental innovations in the automotive industry without disrupting the pre-established architecture; a "non-structured evolutionary development process" that does not allow a proper way to manage complexity and that is strongly product-focused, rather than system-focused - a system from where the product is one of the elements).

In the "design-to-requirements" approach commonly used by engineering firms, product targets get cascaded throughout the vehicle breakdown structure and all the way down to the component level. Traditional automotive ICE OEMs focus on designing products to meet pre- established requirements in the form of targets - usually leveraging reusability of elements in the form of carry over requirements, components or entire subsystems - rather than designing architectures from first principles that meet stakeholders' needs and, therefore, driving a set of system requirements that could be traced back to the need that generated it. While this approach tends to set a "design-to-target" mentality with a potential cost benefit at the component/subsystem Level, further optimization at these same levels often drives associated costs that were not accounted for in the original conception, leading to an exercise of "attribute balancing" which, ultimately, decreases a given cost target from another component/subsystem and, in consequence, limits the number of Levers that can be pulled to foster the inclusion of new technology in the product. Exploiting the potential of the pre-established design by Leveraging reusability of elements and, in fact, previously-established requirements for potential y totally different products, leads to attribute trade-off and discourage of technological advancements that are outside of the pre-established framework. In addition, the time factor (development timing) holds an additional - but most of the time, critical - constraint, since a technology targeted at a certain cost at the beginning of the vehicle development will be affected by multiple market and economic factors that will not be the same after 3 or 4 years; even worse if such technology is "carry-over" from a previous - older – design [11].

4.2 Component knowledge

Incumbent automotive OEMs have not moved away from this "product-oriented" development process largely due to their vast accumulated experience in the development of components or subsystems unfolded from the architecture of the ICE as pre-established dominant design, also known as "component knowledge' (Henderson and Clark 1990). As a matter of fact, component knowledge gets fueled by technological advancements within the boundaries of the selected architecture and, since the dominant design enjoys the acknowledgment and acceptance of one of the most important driving forces, the market, incumbents tend to not recognize or conscientiously demerit any breakthrough that might challenge the status quo. Moreover, since profitability is usually tied to the optimization or refinement of such components of the architecture, it gets very challenging for incumbents to not rely on over-exploiting it; it also enhances the collaboration with other major players in the ecosystem in the development of new component knowledge that could lead to a competitive advantage (e.g. Tier 1 and Tier 2 suppliers) [12]. Component knowledge is, in the context of the design, development and manufacturing of products, the cumulative amount of information and technical expertise acquired from consequently optimizing the components of the system over time and it gets embedded into the core design queues that embody the design concept.

4.3 Architectural knowledge

In contrast to the concept of incremental innovation driven by the component knowledge of incumbents, when architectural innovation arises in an established industry and challenges the supremacy of the dominant design architecture, architectural knowledge stands as the ultimate driving force, and it is usually the new entrant who benefits from being more knowledgeable in that field. Architectural innovation destroys the usefulness of a firm's architectural knowledge but preserves the usefulness of its knowledge about the product's components [13]. Architectural innovation is a new product or process where the interactions between components have been altered in a certain way, without relatively affecting, to a certain degree, the components and the core design concepts. By changing the interaction between the entities within the architecture, the resultant attributes will be different - and perhaps superior, which accumulates knowledge about the architecture for further optimization of the interactions between system entities. In consequence, architectural knowledge tend s to grow, get implicit into practices and processes, until stabilizing as it directly relates to the dominant design architecture; the less a company explores radical solutions to new market, regulatory or economic requirements - stakeholder's needs - the more difficult to untie the knot when a new entrant defies the unthinkable. Both component knowledge and architectural knowledge are required throughout the product development process to increase the probability of success. However, the lack of any such knowledge puts companies at a disadvantage, given the innovation path decided or adopted.

5. Conclusion

Multiple data sources, models and methodologies were reviewed du ring the course of this work to thoroughly evaluate the performance of electric vehicles (EVs) as a technology developed to fulfill the system function of propelling a vehicle and that has seen its best representative in Tesla and the development of a unique architecture, measured against traditional pre-established para meters and attributes for a what a vehicle "should be", and surpassing them in every measurable automotive dimension. In addition to that, identifying Tesla's EV architecture as architectural innovation has revealed that, indeed, the "energy company" possess a substantial competitive advantage against incumbent automotive OEMs seeking to quickly enter into the EV ecosystem; while the cost and impact of completely reconfigure their structure and organization around what is already emerging as an established and potentially dominant vehicle architecture will be significant, these firms must rethink strategic and business decisions previously made based on the ICE vehicle as dominant design and defy their sub-system and component knowledge to quickly start building architectural knowledge, if they truly want to enter into the next chapter the automotive industry [14]. Furthermore, at the system level, incumbent automotive OEMs will need to make decisions around adopting innovative business models to achieve the end - to-end experience and market impact that Tesla has been able to achieve; from owning the majority of the business processes along the product development phase and leveraging vertical integration at multiple levels, to reinventing the concepts of sale showrooms for vehicles, along with an innovative buying experience that includes setting vast expectations via product-unveiling events and a reservations system; to a very personal delivery and - in some cases not necessary - service experience for the end customer, without the need of third parties that only increase the overall cost structure of the product. Finally, EVs are set in a path to market breakthrough and further adoption mostly driven by the success of Tesla and its products not only in California, but throughout the entire world, offering an irrefutably reliable alternative to continue burning fossil fuels to power vehicles; vehicles that up to this day and contingent on how the appearance of new technology and true innovation alters the ecosystem, represent a solution to human transportation. Itis the job of the "regulators" across the globe to develop, as well, innovative and perhaps unthinkable-in-the-past measures to exploit the huge potential of the EV system as a sustainable way to help our environment be less impacted by our need to move from point A to point 8.

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