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Impact of Lean Thinking and Practices on Architectural/System Architectures Level Innovation in Swedish Manufacturing Industry

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ABSTRACT

This thesis analyzes and argues how implementing lean principles and tools affect an organization's architectural innovation. Introducing new product architectures and modifying existing architectures is often difficult for companies. Architectural innovation requires extensive company resources for experimentations and new learning.

Applying lean principles and tools in an innovative organization often make difficulties since innovation focus on active exploration for new solutions within a constantly changing environment (high risks). Whereas, lean focus on eliminating all kind of waste in the system (low risks). Little is known about how lean principles and tools might affect architectural innovation in organizations. Therefore, this research explores the relationship between lean and architectural innovation in manufacturing industries.

The data sample use for this study is Swedish manufacturing companies in seventeen different industry types. The types of industries consist on system level product type such as electrical or/and mechanical integrated products.

Results suggest that in lean principles and tools, standardization, value stream and human resource management (HRM) have significantly positive effect on organization's architectural innovation capability. Whereas, lean design for manufacturability (DFM) has no significant effect on an organization's architectural innovation capability.

This study's findings suggest companies that have not implemented lean thinking and practices yet can adopt lean concepts not only for efficiently utilizing the resources but for improving the architectural innovation also. Furthermore, lean companies should increase their focus on customer involvement in product development as well as in cross-functional training of employees and on job training programs to improve the architectural innovation. Findings suggest that those companies that have strategic focus on architectural innovation can adopt lean concepts and procedures from manufacturing and production departments in order to dramatically increase the architectural innovation.

Keywords: Lean, Architectural Innovation, Standardization, Value Stream, DFM, HRM

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1 INTRODUCTION:

1.1 BACKGROUND:

Today’s competitive and dynamic business environment is placing increased focus on operational efficiencies, high level of quality, and efficient use of resources while maintaining innovation excellences (Peek and Chen, 2011). The concepts of lean enterprise and innovation management have proven to fulfill such demands of global competitive business environment and are well documented (Womack and Jones, 2003; Shah and Ward, 2007; Van de Ven, 1986; Betz, 2011). Innovation provides growth and sustainable competitive advantages to organizations through commercialization of new ideas. The new ideas could be a significantly improved product, service, process, organizational method or business practices (Van de Ven, 1986). Whereas, the lean concepts help the organizations to efficiently utilize limited resources while maintaining high level of quality at low cost, through eliminating unnecessary activities and waste (Hopp and Spearman, 2011; Womack and Jones, 2003). Hence, organizations are striving to be both lean and innovative. To promote innovation and long-term competitiveness, organizations are investing large amount of resources in areas such as research and development projects, outsourcing innovation, and open innovation (Quinn, 2000; Chesbrough, 2006). To implement lean concepts, organizations are employing different methodologies such as lean manufacturing and lean production (Shah and Ward, 2003; Lewis, 2000).

Despite the fact that both lean and innovation are important for companies, some early research has shown conflicts between these two concepts particularly in manufacturing industry. According to Chen and Taylor (2009), lean culture, lean design, lean supply management, and lean human resource management has negative effect on a company’s innovation capability. In particular, the lean design concepts such as standardization and design for manufacturability (DFM) reduce the company’s radical innovation capability (Chen and Taylor, 2012). In contradiction, introducing lean value system in product development through innovative value stream mapping (VSM), facilitates the innovativeness of companies (Schuh, Lenders and Hieber, 2008; Peek and Chen, 2011). Supporting the argument, Plebanek (n.d.) has given a detail framework that lean management approaches are useful to minimize barriers in innovation, by free up resources through waste elimination and dedicating them to innovation. Thus, this conflict between lean and innovation concepts need further research to explore the relationship empirically.

1.2 PROBLEM AREA:

Innovation is a broader concept based on different types of innovations and specific needs of industries. Early research shows that there are different levels of innovation in industries based on different industrial phases and patterns (Abernathy and Utterback, 1978; Abernathy and Clark, 1985). There are four industrial phases such as fluid phase, transitional phase, specific phase, and discontinuities phase. The fluid phase is initial industrial phase where the focus is on functional product performance and development of dominant design. According to Abernathy and Clark, (1985) *"A dominant design is a set of core design concepts that match to the major functions performed by the product and that are embodied in components"*. In dominant design economy of scale is under focus. Hence, architectural innovation is important in fluid phase for the pursuit of dominant design. Once a dominant design is emerged, in transitional phase the industries focus is on product variation and meeting customer needs. Therefore, market niche and regular innovations are important in this phase. In specific phase, the industries focus is on cost reduction and quality improvement with strong focus on customers' needs. Incremental and regular innovations are industries' focus in specific phase. In discontinuities phase, industries face challenges of new technologies invasion, strong competitors' offerings, and market saturation. In this phase, the focus is on exploring new technologies and opportunities i.e radical or revolutionary innovation. The pattern is than cycled back to enforce the architectural innovation in order to develop or modify the dominant design (Abernathy and Utterback, 1978; Roberts and Liu, 2001; Abernathy and Clark, 1985).

Henderson and Clark (1990) distinguish the characteristics of innovation between commercial lives and technological lives. They describe that technology evolution is not fully dependent on the commercial lives of products but it is embodied in the development phase of dominant design, hence in architectural innovation (Henderson and Clark, 1990). Once a dominant design is developed and fundamental structure of product is defined, it is relatively easy to introduce small incremental changes in the established product architecture. Since these small upgrades are sufficient to meet the customer requirements over a long period of time, traditional industries rely on their existing legacy architectures (Hole, 2005). Companies that are unable to change their architecture can miss new business opportunities and new markets (Rechtin, 1992). According to Henderson and Clark (1990), successful companies switch their orientation from many small changes within a establish architecture towards new product architecture. Hence, architectural innovation is a crucial level of innovation for successful industries.

As mentioned in the background discussion, companies are adopting and implementing lean methodologies for efficiently utilizing the resources. Few early researches have shown conflicts in lean and innovation concepts (Chen and Taylor, 2009; Chen and Taylor, 2012). The lean methodologies are generally applied at work environment such as shop-floor, and manufacturing or production space (Womack and Jones, 2003). The lean concepts have direct influence on work environment inside a company rather than on commercial lives of product/services. Hence, the lean concepts can influence the development phase of dominant design. Therefore, it is worthwhile to explore the relationship between lean methodologies and architectural innovation systematically. Lean methodologies are adopted in both service and manufacturing industries (Alsmadi, Almani, and Jerisat, 2012). Whereas, architectural innovation is explicit in manufacturing industries where commercial and consumer oriented products and systems are in focus (Ulrich, 1995). Based on this discussion we formulate our research question as;

What is the impact of lean thinking and practices on architectural innovation in manufacturing industries?

1.3 PURPOSE:

To explore the relationship between lean and architectural innovation in manufacturing industries. To provide propositions to organizations to incorporate both Lean and Architectural innovation concepts.

1.4 THESIS LAYOUT:

The layout of this research is as follows;

In section 2, we review the literature of lean and architectural innovation concepts. In lean concepts, we review the fundamentals of lean thinking and principles, followed by frequent lean manufacturing tools that are used to achieve lean thinking. In architectural innovation concepts, we review the fundamentals of architectural innovation and its key successful factors. Based on this literature review, we develop four hypotheses for exploring the impact of lean on architectural innovation.

In section 3, we present the method of this research and discuss the research approach for testing our hypothesis. Quantitative research method and online survey tool is used for data collection in this research. Whereas, consumer oriented Swedish manufacturing companies with large focus on system level products (electrical, mechanical and hardware integrated) are used as data sample for this research.

In section 4, validity, reliability and unidimensionality of the received data is ensured prior to analysis.

In section 5, hypotheses are tested through statistical methods followed by discussion of results.

In section 6, conclusion is presented based on results and findings of this research. Implications and future research recommendations are also provided in this section.

2 THEORITICAL REVIEW AND FRAME OF REFERENCE:

2.1 LEAN:

2.1.1 HISTORY AND EVOLUTION OF LEAN:

Shah and Ward (2007) describe the history and evolution of lean as follows; the concept and evolution of lean comes from the Henry Ford philosophy and basic principle of assembly lines implemented in 1927. In 1930, Ford and General motors' subsidiaries were dominating the Japanese market and Toyota was struggling with financial problems. Toyota production was disrupted because of World War II. Eiji Toyota (Manager of manufacturing division) started to study other manufacturing practices and he made several trips to Europe and USA and learned about the mass production but because of bad economic conditions the company main focus shifted towards cost reduction by eliminating waste. In 1978, Toyota introduces Toyota Production System (TPS) based on Just-In-Time (JIT) and waste elimination. In 1990, Womack published the book *"The machine that change the world"* which for the first time explained and developed TPS and Lean manufacturing concept. The concept caught the interest of researchers and several research papers were published on the topic. In 1996, Womack and Jones introduce their book "Lean Thinking" that was first attempt to introduce lean in other fields than manufacturing. According to Rinehart, Huxley, and Robertson (1997), lean production has become an integral part of the manufacturing landscape in world. Its link with superior performance and its ability to provide competitive advantage is well accepted among academics and practitioners. Even having its critics, there is no widespread accepted alternatives of lean production. The lean production will be the standard manufacturing mode of the 21st Century.

Lean concepts are generally described from two points of views, either from a conceptual space and philosophical perspective related to guiding principles and overarching goals (Womack and Jones, 2003; Spear and Bowen, 1999), or from a operational space and practical perspective related to set of management practices, tools, or techniques that are corresponds to the conceptual space (Shah and Ward, 2007). In next section, we discuss both of these perspectives. The philosophical perspective is summarized in lean thinking and principles. Whereas, the practical perspective is summarized in lean practices and tools.

2.1.2 LEAN THINKING AND PRINCIPLES:

Womack and Jones are the pioneer of lean thinking and lean principles. Therefore, literature from Womack and Jones (2003) is used in this part to describe the basic principles of lean thinking.

2.1.2.1 Specify Value:

Lean thinking starts from knowing the customers' value. Here value should be defined exactly from the standpoint of the end customer as a specific product that have specific capabilities and offered at a specific time and price (Womack and Jones, 2003).

2.1.2.2 Add Value Stream by Eliminating Waste:

Once the value is specified, the value is added in entire system through value stream and waste elimination. Waste is eliminated in value stream by checking and analyzing the whole value stream for product/s. From customer's point of view, any type of activities that do not add value to a product is waste. Eight types of waste from the standpoint of manufacturing in lean management are as follow;

- Over processing steps
- Waiting time between different operations

- Unnecessary motion, movement, and activities during different operations
- Over production of products
- Bulk Inventory consist of components and unfinished products
- Unnecessary transportation
- Defects and errors in the system that require efforts to inspect and fix (Womack and Jones, 2003).

2.1.2.3 Make the Value Flow:

Once the value stream is defined and waste is eliminated, it is important to make the flow of value in entire system. The flow is created by tight sequences and smooth operation by reducing the complexity of overall system. Standardization of work such is usually implemented in order to improve the flow in a system. The standardization of work is characterized as standardized parts, processes, materials, and compatibility of design with manufacturing (Womack and Jones, 2003).

2.1.2.4 Let the Customer Pull the Process:

Customer' need should be focused by design and delivering time, in other words no design and manufacturing without customers involvement (Womack and Jones, 2003).

2.1.2.5 Pursue Perfection:

When value is specified, value stream is identified, waste is eliminated and customer pull is established, it is then required to repeat the cycle with perfection and improvements in all steps. Here more focus is required on employees' skills improvement and cross-functional work teams (Womack and Jones, 2003).

2.1.3 LEAN PRACTICES AND TOOLS:

To adopt lean philosophy and implement lean thinking, different lean tools or techniques are introduced and implemented in manufacturing companies. Here, we review the most common lean tools that are correspondent to basic lean principles and are evaluated by early research. Table 1 shows different lean tools from previous literature.

Table 1 Common Lean Practices and Tools According to Five Researchers

Lean Tools	1	2	3	4	5
Multifunctional workforce (HRM)	X	X	X	X	
Work standardization	X	X	X		X
Value identification/ Value Stream Mapping (VSM)	X	X			
Cycle time reduction	X		X	X	X
Setup time reduction	X			X	X
Customer requirements analysis	X		X	X	
Parts standardization	X	X	X		X
Design for manufacturability (DFM)	X	X	X		
Cellular manufacturing				X	

(1) Doolen and Hacker, (2005); (2) Eswaramoorthi, Kathiresan, Prasad and Mohanram, (2011); (3) Haque and James-Moore, (2004); (4) Shah and Ward, (2007); (5) Abdulmalek and Rajgopal, (2007)

Based on this review of lean tools, we bundle the same characteristics lean tools in four lean bundles as follows;

2.1.3.1 Lean Value Stream:

Customer requirements analysis, value identification, value stream mapping, and waste elimination such as cycle and setup time reduction, are bundled in lean value stream tool.

2.1.3.2 Lean Standardization:

Lean standardization tool consist on parts standardization and work standardization or standardized process. Whereas, cellular manufacturing is also characterized in standardized process of manufacturing (Shah and Ward, 2007).

2.1.3.3 Lean Design For Manufacturability (DFM):

Lean DFM is about interactions between product design and the units of manufacturing for achieving overall optimization of the system. Here compatibility of new design or product architecture with existing manufacturing process is emphasized (Chen and Taylor, 2012).

2.1.3.4 Lean Human Resource Management (HRM):

The multifunctional workforce is characterized as lean human resource management (HRM). Here, the focus is on multifunctional work teams, cross-functional trainings of employees, improving employees’ skills through job training programs and job rotation (Shah and Ward, 2007).

Table 2 shows the four lean tools/bundles with the correspondent lean principles. Each of lean tools is selected to implement the basic lean principles.

Table 2 Lean Tools vs Lean Principles

Lean Tools/Bundles	Correspondent Lean Principles
Lean Value Stream	Specify Value, Add Value Stream
Lean Standardization	Make Value Flow, Waste Elimination
Lean DFM	Make Value Flow, Waste Elimination
Lean HRM	Pursue Perfection

2.2 ARCHITECTURAL INNOVATION:

2.2.1 HISTORY AND DEFINITION OF ARCITECTURAL INNOVATION:

In 1990, Henderson and Clark identified a new dimension of innovation. They argued that the traditional categorization of innovation as incremental or radical is not complete and a new dimension should be added that is architectural innovation. In order to define the architectural innovation, they distinguished between the components of a product and the ways these components are integrated into the system to develop a product architecture. They defined architectural innovation as changes to the architecture of a product without changing its components and the concept behind it.

According to Henderson and Clark (1990), in radical innovation, the old concepts and designs are destroyed in order to create a new dominant design. The new dominant design is consist on new sets of core design concepts and core components that are linked together in new product architecture. In incremental innovation, individual components are upgraded and the product architecture is refined without disturbing the basic core design concepts and linkages among them. In an architectural innovation, the linkages between core components in a product is change while the core concept of the product is remain untouched. In other words with architectural innovation, the components and concepts of a product remain unchanged but the configuration of the system is changed since new linkages are set up (Henderson and Clark, 1990). As Henderson and Clark (1990, p12) mention,

"The essence of an architectural innovation is the reconfiguration of an established system to link together existing components in a new way."

2.2.2 KEY SUCCESS FACTORS OF ARCHITECTURAL INNOVATION:

According to Henderson and Clark (1990), organizations with emphasis on architectural innovation should focus on active exploration for new solutions within a constantly changing environment. To be successful in architectural innovation two things are important. First, organizations should have knowledge about each component and functions these components perform in a system that is called component knowledge. Second, organizations also should have knowledge about the ways these components can be integrated and linked together as a system that is called architectural knowledge.

Researchers who have studied architectural innovation mentioned some factors that have important influence on successfulness of architectural innovation in the organization. In order to build components and architectural knowledge, organizations need resources like people with required knowledge, money for financing these processes, time for research and development of these concepts, material/technology for making these changes possible, information of market and customers' demands (Gati-Wechsler and Torres, 2008).

Significant interactions and flexibility within the organization are other factors that are needed for architectural innovation. Interactions between different departments in an organization such as workshop and R&D can help in generating and exchanging ideas that is crucial for architectural innovation. Flexibility in organization allows these ideas for experimentation and possibly further implementation (Hole 2005; Van de Ven 1986; Henderson and Clark 1990).

Organizational learning has a direct effect on architectural innovation. For example, engineers/employees in an organization try to improve the performance of their products step by step that usually ends up in architectural innovation. Besides continuous learning, it is also required to investigate new resources and new types of learning by employees as well as by top management. Committed top management that understands the need of change in product/process and encourages experimentation and new learning is a fundamental essence of architectural innovation (Henderson and Clark, 1990; Gati-Wechsler and Torres, 2008; Chen and Taylor, 2009; Lindeke, Wyrick and Chen, 2009; Abernathy and Clark, 1985).

Architectural innovation usually embodied in development of dominant design in order to develop or modify product architecture. A dominant design combines a variety of basic choices about the design that are not reconsidered in every detail. To develop and modify a dominant design, companies perform frequent experimentations and tests. Under these processes, companies make new organizations with different tasks and make new teams of people with different skills. Since nobody in an organization knows about the results of these tests therefore taking risk and time spend on an architectural innovation should not be an issue for the organization (Henderson and Clark, 1990; Van de Ven, 1986; Abernathy and Clark, 1985). Table 3 summarizes the key success factors of architectural innovation.

Table 3 Summarize Key Successful Factors of Architectural Innovation

Architectural knowledge	The ways components can be integrated and linked together as a system
Component knowledge	Have knowledge about each component and task these components do in a system
Need of organization resources	People, Money, Time, Material, Technology, Information, knowledge
Significant interactions within the organization	Communication between different departments in an organization for generating ideas.
Flexibility in organization	Ability to make changes in organization and production often and fast.
Ability/requirement to investigate new resources/types of learning	To make new knowledge by internal or external resources. Bringing in new knowledge by hiring new people or by buying new technologies.
Organizational/top management decision making/commitment and learning	Making innovation a fundamental part of business by having strong leadership and long term strategies.
Need of dominant design and building knowledge	Usually combines a variety of basic choices about the design that are not reconsidered in every detail.
Continues learning (updating knowledge)	The design team frequently experiments on the existing components for new product designs
Need of different kind of organization and different people with different skills	Different kind of architectural innovation need different kind of organizational environment and people with different skills.

Uncertainty and encourage risk-taking	Capacity to take risk since nobody knows the results of the resources on the final products..

2.3 LEAN AND ARCHITECTURAL INNOVATION:

2.3.1 LEAN VALUE STREAM AND ARCHITECTURAL INNOVATION:

According to Henderson and Clark (1990), the new architectural knowledge, new knowledge of components and new knowledge of linkages among the components is crucial for architectural innovation. Once a dominant design is emerged, the successful companies focus on refining the existing configuration and linkages of stable design through new learning and new knowledge of the components and concepts. The new knowledge is also developed by establishing communication channels and interactions among the different participants of product design. The participants could be different departments and different people such as design engineers, shop-floor employees, production, development, and research departments etc. The shared information and knowledge through these communication channels and interactions become the catalyst of new architectural knowledge (Henderson and Clark, 1990).

Establishing communication channels and sharing information with customers may provide new architectural knowledge, since they are the one who pay for the product and utilize product features and attributes (Plebanek, n.d.; Schuh et al., 2008). Customers do not possess knowledge of the core components and core concepts of the product. However, they are the potential users who explore the product features in practical settings and nor the manufacturer. Customers may identify the need of new product architecture based on their requirements of new features and attributes in existing products or product line. Customers can also identify new linkages among product features and attributes, particularly when the product type is manufacturing and process machines, instruments and integrated industrial products that are used in conjunction with other products. In lean concepts, customer value is the essence of lean thinking and practices. It is customer value that distinguishes between waste and non-waste in a lean company. Values to the customers are provided by value propositions (reduced cost or time) or by providing extra features and attributes in products that customers are willing to pay (Womack and Jones, 2003). Hence, involving customers in product development process (specifying and mapping customer values) may provide ideas about new product architecture and linkages, that can be explored by design team to develop a new product architecture.

According to Henderson and Clark (1990), developing new product architecture and new architectural knowledge is not easy. It requires lot of experimentation and resources (money, time, and people). In early stages of technology changes, before the emergence of dominant design, companies are competing to experiment and develop new product design with many different technologies. Companies actively develop both knowledge of alternate components and the knowledge of how these components can be integrated together. Once a dominant design is emerged and well accepted, the companies' limited attention shifted from creating new product architecture towards refining the components in established architecture (incremental, regular innovation). In order to exploit an architectural innovation, the companies must change their orientation from refining within the established architecture towards actively search of new solutions to build a new architectural knowledge. Once companies successfully change their orientation towards building of new architectural knowledge, it takes lot of time and company resources. Building new knowledge may require destroying the previous knowledge and commitment to older ways of learning. It requires frequent experimentation, building and modifying communication channels and filters in information exchange, time span to conduct and test new product architecture, and the resources to help this new learning (Henderson and Clark, 1990).

Resources such as excess time, money and employees interaction can also achieved by lean waste elimination. The lean value stream concepts focus on eliminating waste based on specified customer values. By eliminating waste, it is ensured that only value added activities are added into a company's operations. Elimination of waste releases the companies' resources and allows use of resources in more efficient way. For example, eliminating over processing steps reduce the cost of production, reduce complexity in manufacturing process, reduce processing time, and require less interaction of employees. Similarly, by eliminating waiting time in entire production and development process, companies free up excess time (Womack and Jones, 2003).

Based on the discussion we can say that, by specifying and mapping customer values, and by eliminating over processing steps and waiting time based on customer values, improves architectural innovation in manufacturing companies. In lean concepts, these characteristics are generalized as lean value stream. Therefore our first hypothesis is;

Hypothesis 1: Lean value stream has positive effect on architectural innovation

2.3.2 LEAN STANDARDIZATION, LEAN DFM AND ARCHITECTURAL INNOVATION:

According to Johnstone et al., (2011), standardization is often understood as a process that is against innovation since the focus is on "right way" and not on new ways. Standardization defines the way process should be accomplished by eliminating non-value adding activities. In standardization, processes should be followed in right routinised orders. Because of standardization, product design usually gets less attention since creativity is not inspired in the design processes (Chen and Taylor, 2009; Chen and Taylor, 2012). In DFM, main goal is to design a product that can be easily and economically manufactured through existing manufacturing processes. DFM is achieved through product simplification by re-using the existing parts and processes (Taylor and Chen, 2009).

As mentioned earlier in architectural innovation, linkages among core components and among core concepts are needed to modify in order to develop new product architecture. The development of new product architecture may require new process, new routines and even new parts that are against the standardized process. Standardization's concepts do not allow architectural innovation to change the routines of product manufacturing in a company. The new required process may also required new parts and new manufacturing processes that are not compatible with existing manufacturing process. Therefore, DFM's concepts also do not allow architectural innovation to change product design to a new design that requires large changes in the manufacturing process.

DFM and standardization are based on existing knowledge, processes and components. Whereas, architectural innovation requires building new knowledge by changing processes and component linkages in new product design, that may require destroying the previous architectural knowledge. Based on this discussion, we develop our second and third hypothesis as follows;

Hypothesis 2: In lean practices, standardization has negative effect on architectural innovation.

Hypothesis 3: In lean practices, DFM has negative effect on architectural innovation.

2.3.3 LEAN HRM AND ARCHITECTURAL INNOVATION

As mentioned above components and architectural knowledge are two dimensions of architectural innovation. These two knowledge dimensions come mainly from inside of the company by employees (Hole, 2005) who are actually working with the components and systems at shop-floor. In order to have architectural innovation, organizations need to be flexible, have different kind of people with different skills, and have significant interactions within the organization. The interactions are made useful through ideas exchanging between multi-skilled employees. In lean thinking, workers are expected to increase their involvement in teamwork, problem solving, and reengineering setups in order to perform multiple types of tasks or functions. Therefore, employees' skills are efficiently utilized in a company (Mehta and Shah, 2005).

Plebanek (n.d.) mentioned, in lean practices managers by eliminating activities that are waste from employees' responsibilities can free up resources and commit the employees to innovation. Knowledge building is gained usually by job rotation which helps development of multi skill employees which is needed for lean manufacturing (Gati-Wechsler and Torres, 2008). Hence, skilled employees and multifunctional work teams do not only improve the efficiency, but can also improve architectural innovation through cross-functional skills and interactions (Hole, 2005). Based on this discussion we develop our fourth hypothesis as follows;

Hypothesis 4: In lean practices, lean HRM has positive effect on architectural innovation.

Figure 1 shows our hypothetical framework.

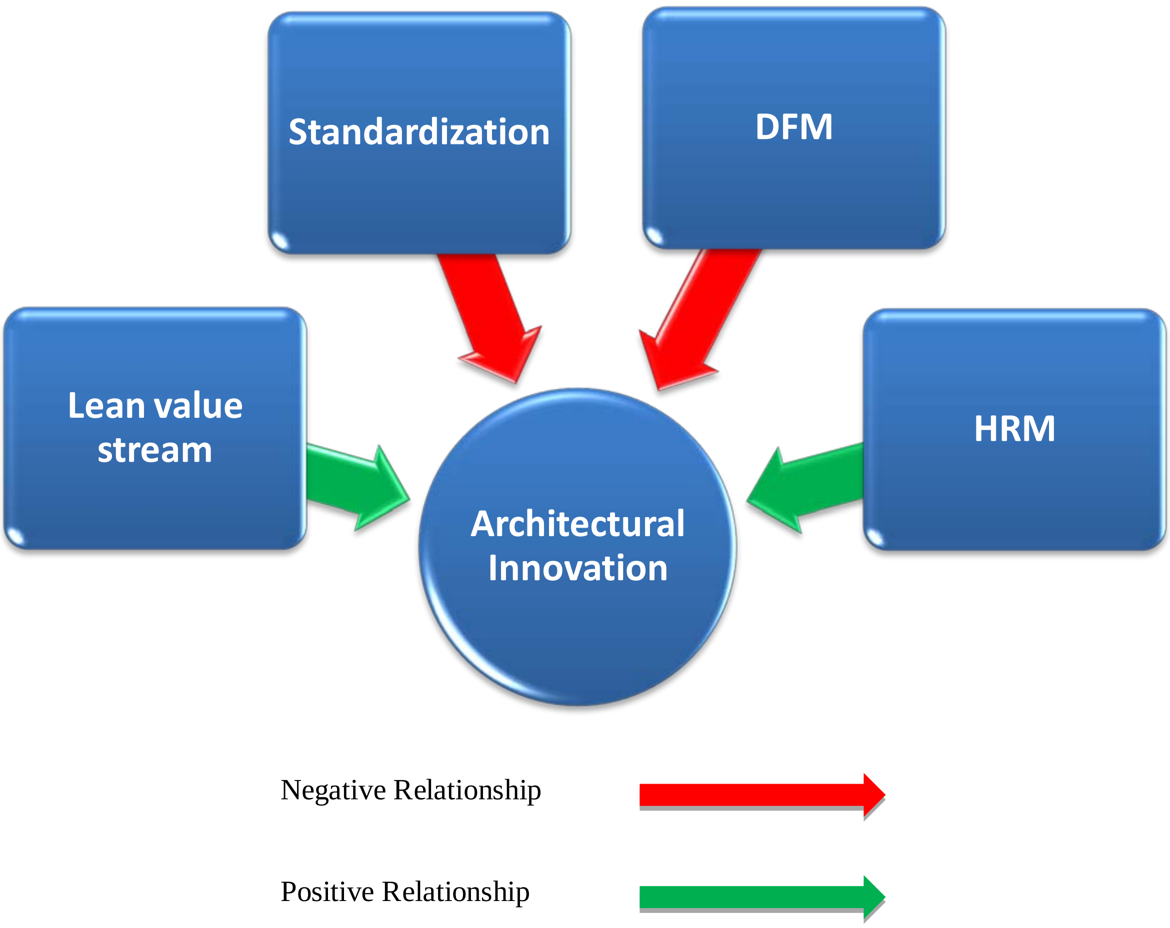


Figure 2 Hypothesize Impact of Lean over Architectural Innovation

3 METHODOLOGY:

3.1 RESEARCH APPROACH:

Our Research Question is: What is the impact of lean thinking and practices on architectural innovation in manufacturing industries? Here, the relationship between architectural innovation and lean thinking and practices is in focus. According to Bryman and Bell (2011), deductive research is in focus during quantitative research. Since the field is broad, our focus is on exploring the underlying relationship. Furthermore, previous researches e.g. Chen and Taylor (2009; 2012), base their studies on large number of companies that they studied more on surface. Therefore, we chose quantitative research approach in order to explore relationship between architectural innovation and lean. This choice is based on the fact that the field of lean and architectural innovation is broad exploratory subject.

3.2 LITERARY SOURCES:

Databases used for literary sources are the following: Harvard Business Review, Directory of Open Access Journals, International Encyclopedia of the Social and Behavioral Sciences, ProQuest, Google Scholar, IEEE Xplore, Retriever Bolagsinfo. Key words used to search the databases were: Innovation, Architectural Innovation, Innovation Management, Lean, Lean Tools, Lean Principles, Lean Thinking, Lean Management and Lean Production. The most common names used were: Henderson and Clark (1990), Abernathy and Clark (1985), Chen and Taylor (2009), Shah and Ward (2007). Articles that map the architectural innovation field proved mostly useful, especially Henderson and Clark (1990) and furthermore, articles that map the Lean field proved mostly useful, Taylor and Chen (2009), Shah and Ward (2007).

3.3 DATA COLLECTION:

For testing each of hypotheses stated above, we develop measurement questions for lean and architectural innovation separately. We develop 24 lean measurement questions and group them in four independent variables correspondent to our four hypotheses defined in literature. The four independent variables are shown in Table 4. For architectural innovation measurement, we develop eight measurement questions based on the key successful factors of architectural innovation, defined in literature. These questions are grouped in one dependent variable as shown in Table 5. All the questions are then transformed in to an online survey questionnaire both in Swedish and English language. The survey consists of 32 closed questions answered on 5 levels Likert scale. Three control questions are also included regarding the position of the respondent, company size and company name. However, the company names are kept anonymous and used only for identification of the responses. The company size and position of respondent is used to ensure the significance of the responses. To avoid bias response, the term “architectural innovation” and “lean” is not directly used in the questionnaire. Google Forms is used as a survey instrument because of its feasibility of unlimited questions and responses. Furthermore, in Google Form, the responses are added automatically to a spreadsheet that is easy for importing bulk data for analyzing. The survey questionnaire is attached in the Appendix. The targeted respondents of our survey are production and/or R&D managers because of relevancy of our survey questions and validity of our data. Therefore, we distribute the survey questionnaire to the production and/or R&D managers of different companies by personal e-mails. The companies that did not response after first and second week were contacted again through phone and email.

Table 4 Four Independent Variables of Lean and Measurement Questions/Items

Independent Variables (Lean)	Items
1. Lean Value Stream	Customer involvement in product development; matching customer requirements with product features and attributes; Identify and allocate new resources based on customer requirements; Strict with time and deadlines in product development; Eliminate waiting time between final product and intermediate product; Continuously revise processing steps in product development; Eliminate over-processing steps (Karlsson and Åhlström, 1996; Womack and Jones, 2003).
2. Standardization	Use of standardized components, and standardized process in product development (Haque and James-Moore, 2004)
3. Design for Manufacturability (DFM)	Compatibility of product design with current manufacturing process; Avoid new designs that requires dimensional changes, high cost and longer time in manufacturing, in existing manufacturing process.
4. Lean HRM	Involvement of shop-floor employees in product development; Emphasize on cross-functional work teams, cross-functional training of employees (Karlsson and Åhlström, 1996); Job rotation and job training programs.

Table 5 One Dependent Variable of Architectural Innovation and Measurement Questions/Items

Dependent Variable (Architectural Innovation)	Items
1. Architectural Innovation	Emphasize on changing product architecture through modifying the linkages among core components/core concepts; Develop new knowledge about possible linkages among core components/core concepts; Allocate resources supporting ideas of new product architecture; Encourage interactions among different departments in organization for product development;

	Flexible experimentation on re-organizing the existing components for new product architecture; Top management commitment for ideas regarding new product architecture (Henderson and Clark, 1990).

3.4 SAMPLING:

To find companies that can provide valuable and relevant input for our studies, we search for similar studies within the field of lean and Innovation. As defined in literature, manufacturing companies are implementing lean at greater extent as compare to service companies. Whereas, architectural innovation is related to companies that are manufacturing system level products i.e products that are based on several components and parts integrated together. We use "Retriever Bolagsinfo" database in order to search manufacturing companies and found total 45331 manufacturing companies in different industrial sectors (Retriever Bolagsinfo, 2014). We chose 17 industrial sectors that are most suited for architectural innovation based on system level product type as shown in table 6. According to Ulrich (1995), architectural innovation is explicit in consumer oriented product type where high-level integration of electrical and/or mechanical parts exists.

Table 6 Types of Manufacturing Industries based on System Level Products

S.No	Industry Type
1.	Computers & Peripheral Manufacturing
2.	Electrical Equipment Manufacturing
3.	Electric Home Appliances Manufacturing
4.	Electrical Components and Circuit Boards Manufacturing
5.	Electronics Industry
6.	Consumer Electronics Manufacturing
7.	Agriculture & Forestry Machinery Manufacturing
8.	Communications Equipment Manufacturing
9.	Office Machinery Manufacturing
10.	Machinery Manufacturing
11.	Medical and Dental Instruments Manufacturing
12.	Motorcycles Manufacturing
13.	Engines and Turbines Manufacturing
14.	Motor Vehicle Manufacturing
15.	Optical Instruments and Photographic Instruments

16.	Rail Vehicles Manufacturing
17.	Textile Weaving Machines Manufacturing

An important theoretical consideration for this study is size of the companies. The survey questionnaire is aimed to ask from production managers and /or R&D managers for lean and architectural innovation measurements respectively. In very large organization, the production and R&D facilities are usually not under the same roof. Hence, it is difficult to collect the data from two different departments in a company simultaneously, through survey questionnaire. Therefore, we chose the company size between 20 to 250 employees that is the EU's definition of small and medium size companies (European Commission, 2014). These types of companies usually have production and R&D departments under the same roof that is important for our research. At the end of sample selection, Retriever Bolagsinfo gave us 672 companies matched with our initial sample criteria. These 672 companies were checked carefully in order to eliminate contract manufacturer, manufacturing service providers and irrelevant product type companies. Total 338 Swedish manufacturing companies found that matched with our final sampling criteria and that can provide us a reliable data for this research (Retriever Bolagsinfo, 2014).

3.5 DATA ANALYSIS TECHNIQUES:

3.5.1 RELIABILITY AND UNIDIMENSIONALITY:

As described in the data collection part of this thesis, four independent variables for lean measurement and one dependent variable for architectural innovation measurement are developed. All these variables consist on scale multi-items that are also defined in the data collection part. Before testing and analyzing the hypotheses, it is important to test reliability of multi-item variables as well as uni-dimensionality of reliable variables. Using unreliable data variables can lead to situations in which either a hypothesis test is criticized for generating untrustworthy results, or a hypothesis test is wrongly discarded (Tavakol and Dennick, 2011). In statistical methods, the reliability of multi-item variable is tested by determining Cronbach's alpha coefficient (Alpha) value that is between 0 to 1. According to Gliem and Gliem (2003), a rule of thumb for reliability test based on Alpha values is given in table 7.

Table 7 Rule of Thumb for Reliability Test based on Alpha Values

Reliability based on Alpha Value
1 > Excellent ≥ 0.9
0.9 > Good ≥0.8
0.8 > Acceptable ≥ 0.7
0.7 > Questionable ≥ 0.6
0.6 > Poor ≥0.5
0.5 > Unacceptable

The uni-dimensionality of reliable variables is tested by determining item-to-total correlation values (correlation coefficient values of each item with total variable) that is between 0 to +1. A higher correlation value indicates higher uni-dimensionality of the scale items in a multi-item variable. Whereas, items with correlation values less than 0.3 does not show correlation with overall variable and must be eliminated.

3.5.2 CORRELATION MATRICES:

We use correlation matrix to find the relationship of each lean independent variable with architecture innovation dependent variable. A correlation matrix indicates the individual relationship of two variables while ignoring the influence of all the other remaining variables (zero-order correlation). This zero-order correlation is measured by determining the value of correlation coefficient (r) that is between 0 to ±1. A higher positive value represents a good positive relation and a higher negative value represents a good negative relation. Significance of correlation is measured. The value of correlation coefficients are given at specific significance level and are generally represented as number of asterisks i.e. Sig. level: * < 0.05; ** < 0.01; *** < 0.001.

3.5.3 MULTIPLE REGRESSION ANALYSIS:

We used multiple regression analysis to analyze our data. To determine the variance of a dependent variable based on combinations of multiple independent variables, multiple regression analysis can be used. In other words, multiple regressions is used when we want to calculate the variance of a variable based on the value of two or more variables. R-square value in multiple regression analysis finds the percent of variance in the dependent variable explained by the independent variables and shows how well the model matches the overall data. Higher level of R-square means better the level of variability calculated for defined items in the given model. Other important value is F-value. The F-values describe the significance of the R-squared value, or the whole significance of the regression model (Cohen, Cohen, West, and Aiken, (2003); Von Eye and Schuster, (1998).

Each of our hypotheses is tested through multiple regression analysis. Architectural innovation variable is entered as the dependent variable. Whereas, lean variables are entered as independent variables. Two methods of multiple regression analysis are used. In first method, all independent variables are entered together to determine the variance of dependent variables based on all independent variables together “Enter method”. In second method, stepwise approach is used. Stepwise multiple regression analysis method is used to determine the entry order of each independent variable. This approach indicates the best subset of independent variable that explain the largest variance in dependent variable or on the overall model, based on the maximum change in R-square value.

4 RESULTS:

4.1 SURVEY DISTRIBUTION RESULTS:

The sample frame for this research consists of 338 companies in 17 different industries as mentioned above. Total 37 responses received out of 338 that give a response rate of approximately 11%. This is relatively a moderate response rate as compare to the small sample size. The average response rates for such studies are 12 % (Chen and Taylor, 2012). Relevant respondents such as production, R&D, design, construction and other managers answered all the responses. None of the response is uncompleted because of using the “required question” option in Google Form. Hence, all responses are used for the analysis. Table 8 is a summary of survey distribution results.

Table 8 Summary of Survey Distribution Results

No. of Survey Distributed	No. of Responses Received (N)	Response Rate (%)
338	37	Approx 11 %

4.2 RELIABILITY AND UNIDIMENSIONALITY TEST:

In this section, we ensure the reliability and unidimensionality of received data in each lean and architectural innovation variables.

4.2.1 LEAN VARIABLES:

The four lean measurement variables are; Value_Stream; Standardization; DFM; and HRM. The alpha and item-to-total correlation values of each multi-item lean variable is determined and shown in Table 9.

Table 9 Reliability and Unidimensionality Test of Lean Variables

S.No	Variables	Items (5 level Likert Scale)	Mean	S.D	Item to Total Correlation
1.	Value_Stream Alpha: **0.794** Mean: 3.8 S.D: 0.628	Cust_Value_1	4.0	0.882	**0.595**
		Cust_Value_2	4.19	0.845	**0.635**
		Cust_Value_3	4.16	0.928	**0.634**
		Cust_Value_4	3.81	0.908	**0.674**
		Waste_Time_1	3.51	1.239	**0.755**
		Waste_Time_2	4.00	1.000	**0.536**
		Waste_Processing_1	3.27	0.962	**0.643**
		Waste_Processing_2	3.46	1.043	**0.652**
2.	Standardization Alpha: **<u>0.540</u>** Mean: 2.816 S.D: 0.624	Standardization _1	3.11	1.149	**0.748**
		Standardization _2	3.14	1.004	**0.634**
		Standardization _3	2.51	0.901	**<u>0.459</u>**
		Standardization _4	3.19	1.221	**0.637**
		Standardization_5	2.14	0.948	**<u>0.456</u>**
3.	DFM Alpha: **0.748** Mean: 3.135 S.D: 0.769	DFM_1	3.00	0.972	**0.743**
		DFM_2	2.68	1.029	**0.627**
		DFM_3	3.51	1.017	**0.805**
		DFM_4	3.35	1.060	**0.843**
4.	HRM Alpha: **0.790** Mean: 3.378 S.D: 0.740	HRM_1	3.32	0.944	**0.558**
		HRM_2	3.65	1.060	**0.840**
		HRM_3	3.22	0.886	**0.812**
		HRM_4	3.35	1.160	**0.785**
		HRM_5	3.35	0.949	**0.691**

Table 9 shows that Value_Stream, DFM, and HRM have alpha values greater than 0.7 as well as these variables have high item-to-total correlation. Hence, these variables are well reliable and uni-dimensional for testing the hypotheses. The standardization variable shows the lowest item-to-total correlation in two of its scale items that are standardization_3 (0.459 correlation) and standardization_5 (0.456 correlation). The alpha value is also low (0.54) in this case. Therefore, items standardization_3 and standardization_5 are eliminated from this variable. The new standardization variable with improved alpha (0.658) and improved over all item-to-total correlation is shown in Table 10.

Table 10 Reliability and Unidimensionality Test of Improved Standardization Variable

Variable	Items (5 level Likert Scale)	Mean	S.D	Item to Total Correlation
Standardization Alpha: **0.658** Mean: 3.144 S.D: 0.869	Standardization _1	3.11	1.149	**0.827**
	Standardization _2	3.14	1.004	**0.814**
	Standardization _4	3.19	1.221	**0.689**

4.2.2 ARCHITECTURAL INNOVATION VARIABLE:

The one dependent variable for architectural innovation measurement consists of 8 scale items. Table 11 shows the alpha value and item-to-total correlation of architectural innovation variable. The alpha value is 0.848 and the item-to-total correlation value is high in all the scale items that yield the architectural innovation variable also reliable and uni-dimensional.

Table 11 Reliability and Unidimensionality Test of Architectural Innovation Variable

Variable	Items (5 level Likert Scale)	Mean	S.D	Item to Total Correlation
Architectural_Innovation Alpha: **0.848** Mean: 3.334 S.D: 0.699	Arch_Inno_1	3.11	0.906	**0.714**
	Arch_Inno_2	2.92	0.894	**0.639**
	Arch_Inno_3	3.43	0.899	**0.614**
	Arch_Inno_4	3.41	0.956	**0.804**
	Arch_Inno_5	2.81	1.101	**0.792**
	Arch_Inno_6	3.95	0.911	**0.640**
	Arch_Inno_7	3.54	1.043	**0.659**
	Arch_Inno_8	3.51	1.261	**0.721**

5 DATA ANALYSIS AND DISCUSSION:

Going back to the discussion of theoretical framework, we developed four hypothesis for this research mentioned in Table 12.

Table 12 Four Hypotheses Developed for this Research

Hypothesis 1	Lean value stream has positive effect on architectural innovation
Hypothesis 2	Lean standardization has negative effect on architectural innovation.
Hypothesis 3	Lean DFM has negative effect on architectural innovation.
Hypothesis 4	Lean HRM has positive effect on architectural innovation.

Before final testing of hypothesis, we construct a correlation matrix in order to determine the individual relationship of all lean and architectural innovation variables. The correlation matrix of lean and architectural innovation variables are shown in Table 13.

Table 13 Correlation Matrix of Lean and Architectural Innovation Variables

	Architectural Innovation	**Value_Stream**	**Standardization**	**DFM**	**HRM**
Architectural Innovation	1	**0.446****	**0.282***	**0.052**	**0.442****
Value_Stream	0.446**	1	0.200	0.163	0.289*
Standardization	0.282*	0.200	1	0.413**	- 0.081
DFM	0.052	0.163	0.413**	1	0.144
HRM	0.442**	0.289*	- 0.081	0.144	1
Sig.(1-tailed)	Sign.: * < .05; ** < .01; *** < .001				
Responses	N = 37				

Our hypothesis 1 states, “Lean value stream has positive effect on architectural innovation”. Table 13 shows that there is 44.6 % statistical significant positive correlation between lean value stream and architectural innovation. Hypothesis 2 states, “Lean standardization has negative effect on architectural innovation". This should show a negative correlation between lean standardization and architectural innovation. However, our matrix shows a significant positive correlation between lean standardization and architectural innovation. Hypothesis 3 states, "Lean DFM has negative effect on architectural innovation". The matrix shows there is no significant correlation between lean DFM and architectural innovation. Hypothesis 4 states, "Lean HRM has positive effect on architectural innovation". The correlation matrix shows, there is 44.2 % statistical significant positive correlation between lean HRM and architectural innovation.

Each of the hypotheses is now finally tested through multiple regression analysis. The results of multiple regression analysis based on "Enter method" are shown in Table 14.

Table 14 Results of Multiple Regression Analysis using "Enter Method"

	Architectural Innovation
Lean Value Stream	**0.291****
Lean Standardization	**0.338****
Lean DFM	- 0.194
Lean HRM	**0.414******
R-Square	**0.398**
R-Square (adjusted)	**0.322**
F Change	**5.283******
	Sign.: * < .05; ** < .01; *** < .001
	No. of Responses N = 37

Hypothesis 1:

The regression analysis model in Table 14 shows that the lean variables explain approximately 40 % variance (R-square = 0.398) of the innovation variable or the overall model. The F Change is 5.283 at two asterisk significant level that shows the overall model is good fit. Our hypothesis 1 states that lean value stream has positive effect on architectural innovation. The model supports this hypothesis since the lean value stream variable has positive beta value (0.291) at one asterisk significant level.

Hypothesis 2:

Our hypothesis 2 states that lean standardization has negative effect on architectural innovation. It was expected to have a negative beta value of lean standardization and architectural innovation for the support of this hypothesis. The results rejected the hypothesis 2 and shows a positive relationship (b = 0.338) between lean standardization and architectural innovation at significance level as shown in Table 14. The correlation matrix between lean standardization and architectural innovation variables also shows 28% positive correlation at significant level. To further investigate this result, we test the correlation of each item of the standardization variable with architectural innovation. It is found that emphasizing on standardized components during product development has 31% significant positive correlation with architectural innovation. Moreover, the standardized product development process accounts for approximately 25% positive correlation with architectural innovation at significance level of 0.068. Hence, the standardized parts and standardized process in product development may results dramatic increase in architectural innovation. One reason behind this could be that non-standardized and differentiate components may require additional time and efforts for experimentation, and are therefore not considered in product development. Standardized components and standardized process may make it easier and less complex to explore the possible linkages among the components.

Hypothesis 3:

Our hypothesis 3 states that lean DFM has negative effect on architectural innovation. This hypothesis is also rejected by the results since there is no statistical significant between lean DFM and architectural innovation as shown in Table 14. To analyze further, we test the correlation matrix of each lean DFM item with architectural innovation variable. The matrix shows that none of the lean DFM items has significant correlation with architectural innovation. Hence, it is found that emphasizing on the compatibility of product design with existing manufacturing process has no effect on the architectural innovation. Furthermore, by avoiding the designs that require dimensional changes, as well as high cost and longer time for manufacturing in existing manufacturing process, can only improve the overall efficiency while not effecting the architectural innovation. A reason behind this can be that a new product architecture developed by modifying the linkages among established and existing components can still be compatible with the existing manufacturing process and not requires any major changes.

Hypothesis 4:

Our last hypothesis 4 states that lean HRM has positive effect on architectural innovation. The results show a positive value of regression coefficient (0.414) at significance level of two asterisks for the lean HRM variable as shown in Table 14. This supports our hypothesis 4.

The results of stepwise multiple regression analysis are shown in Table 15. Lean value stream variable shows the maximum F Change value (8.698) and ranked in the first model of stepwise regression analysis. Hence, among lean variables, the lean value stream shows the strongest relationship with architectural innovation while the lean HRM comes on second order.

Table 15 Results of Stepwise Multiple Regression Analysis

	Architectural Innovation	
	Model 1	Model 2
Lean Value Stream	0.446**	0.346*
Lean HRM		0.342*
R-Square	0.199	0.306
R-Square (adjusted)	0.176	0.265
F Change	**8.698****	5.252*
	Sign.: * < .05; ** < .01; *** < .001	
	No. of Responses N = 37	

6 CONCLUSION:

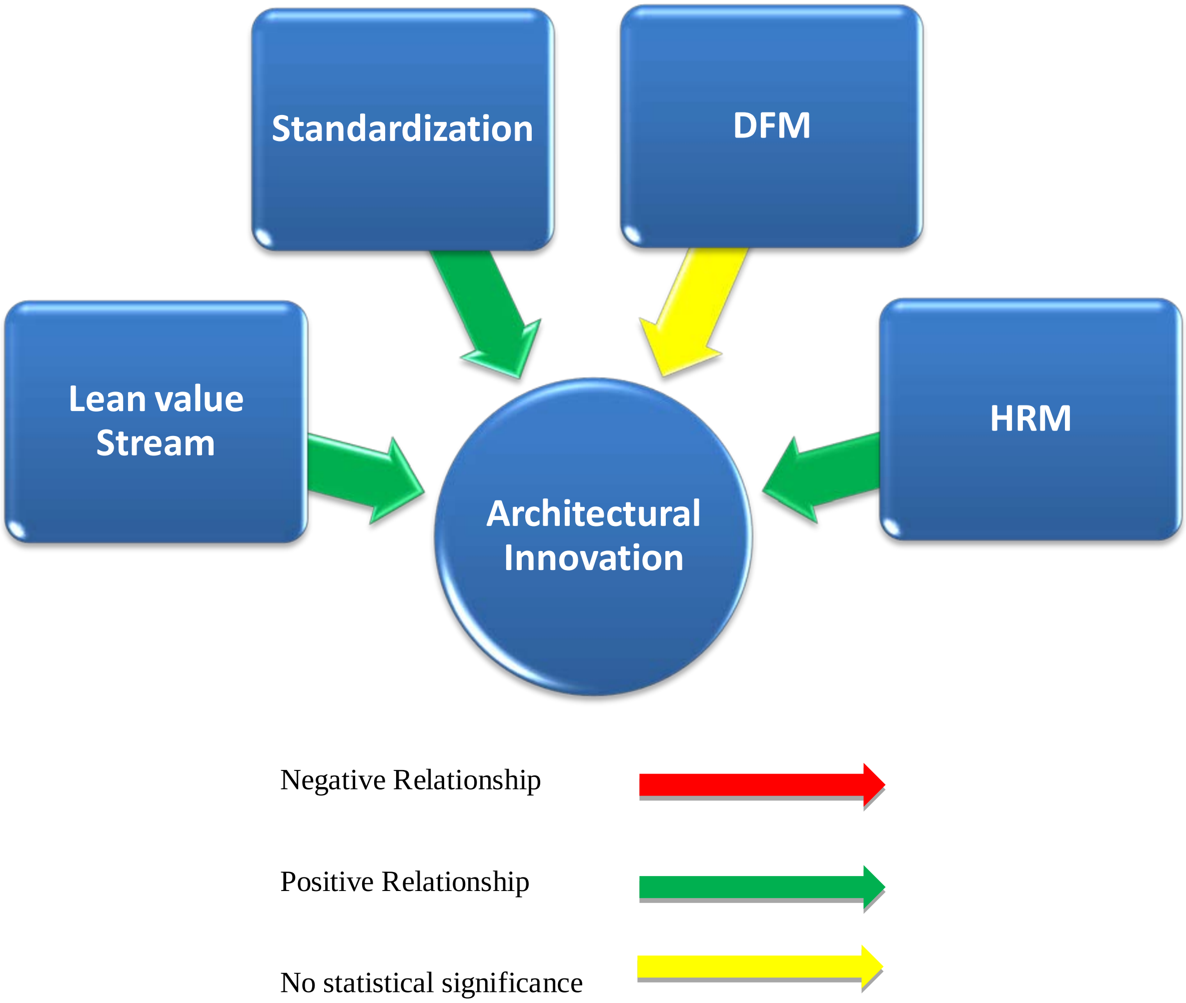
Our research question was to explore the relationship of lean thinking and practices with architectural innovation in manufacturing industries. Four hypotheses were proposed to test lean characteristics and their impact on architectural innovation. Lean value stream, lean standardization, lean DFM and lean HRM are those lean characteristics that are used to explore this relationship through an online survey and statistical analysis.

Our Results support that implementing lean value stream thinking in manufacturing industries; significantly improve the architectural innovation excellence through involving the customers in product development process. Customer ideas and requirements provide new knowledge to the manufactures about product architecture of established products. Based on this new knowledge, companies can modify their established knowledge hence modify the established product architecture. To develop new product architecture, companies needed extra resources. Results validate that in lean value stream, eliminating waiting time and over processing steps based on customer values, improve the architectural innovation in companies. Hence lean value stream also free up the companies' resources that can be used for developing new product architecture.

Results also support that lean HRM increases the architectural innovation capabilities in manufacturing industries. In order to investigate and modify the linkages among core components of established products, cross-functional skilled employees and continuous learning of new knowledge is crucial. Our results show that in lean HRM, involvement of shop-floor employees in product development process; emphasizing on cross-functional work teams and cross-functional training of employees; and emphasizing on job rotation and job training programs increase the architectural innovation in manufacturing industries.

According to our findings, lean DFM has shown no significant relationship with architectural innovation. Based on this finding we can conclude that modifying the product architecture within in the established framework does not require major changes in the manufacturing process. Hence, the lean DFM tool can be generally used in manufacturing industries to ensure simplicity and to improve efficiency without effecting the architectural innovation.

In contradiction to our prior understanding of the relationship between lean standardization and architectural innovation, the results show that architectural innovation increases with an increased focus on standardized components and standardized process. Figure 2 shows the findings of our research.



Figur 3 Impact of Lean over Architectural Innovation

6.1 IMPLICATION:

Our research findings are useful for manufacturing industries on the account of increasing efficiencies as well as improving architectural innovation excellence. Companies that have not implemented lean thinking and practices yet can adopt lean concepts not only for efficiently utilizing the resources but for improving the architectural innovation also. Companies that are already using lean methodologies can increase architectural innovation by improving lean value stream and lean HRM practices. It is suggested that companies should improve the relationship with customers not only for increasing sales but to involve customers in product development process for increasing architectural innovation and competitive advantage. Furthermore, lean companies should increase their focus on cross-functional training of employees and on job training programs to improve the architectural innovation.

6.2 LIMITATIONS AND FUTURE WORK:

The limitations of this research work includes less number of responses (37) because of relatively small sample size (338 companies), and the survey questionnaire design. A larger sample with more responses would lead to higher confidence in the research results. In survey questionnaire, more measurements of lean and architectural innovation variables would provide in-depth measurement of the concepts.

The standardization concept of lean is most often criticized when the influence of lean on innovation is discussed. Our research finding shows a significant positive impact of standardization over architectural innovation. However, this finding is based on less number of responses and few measurements of standardization. Future research can explore the impact of standardization over architectural innovation with detail measurements of both concepts.

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APPENDIX

Survey Questionnaire

* Required

Instructions:

We are grateful and pay sincere thanks to the company and the individuals who participate in this survey. Please answer all questions by selecting the number that best capture your perspective.

1 Strongly disagree   2 Disagree   3 Neutral   4 Agree   5 Strongly agree

If a black asterisk (*) following a word, this word is defined in the definition list below.

Definitions:

*Core Components: The major functional components or major elements of a product or a system. OR, one of several parts that together make up a whole machine, system etc.

*Core Concepts: The major concepts of building a product or the major configurations of a system, product etc.

*Linkages: Relationships, interactions and links among different components or among different concepts.

*Product Architecture: The way in which the functional elements of a product are arranged into physical units and the way in which these units interact.

*Intermediate Product: An intermediate product is a product that might require further processing before it is saleable to the end consumer. OR, a prototype that might need more lab testing and documentation.

*Routinized Process: Standardized process of product development such as routines, scheduling etc.

General Questions:

1. Name of your Company *

2. Your position in the Company

3. Number of Employees in your Company

Questionnaire Part One: Production and Manufacturing

1. We emphasize on end customers' involvement in product development. *

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

2. We always ask our end customers about their needs and requirements. *

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

3. We matched the customer requirements with design features and attributes of product during product development *

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

4. Based on our customer requirements, we identify and allocate new resources. *

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

5. We are strict with time and deadlines in product development. *

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

6. We emphasize on reducing waiting time between final product and intermediate product*. *

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

7. Our employees are engaged in too many activities during product development. *

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

8. We exchange too much information during product development. *

1 2 3 4 5

Strongly Disagree ○ ○ ○ ○ ○ Strongly Agree

9. We continuously revise the processing steps in product development. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

10. We emphasize on eliminating over-processing steps in product development. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

11. Components* are frequently standardized in our company. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

12. In product development, we use standardized components. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

13. In product development, it is hard to make modifications because of standardized components. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

14. Our product development process is routinized*. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

15. In product development, it is hard to make modifications because of routinized process. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

16. In new product development, compatibility of product design with current manufacturing processes is emphasized. *

	1	2	3	4	5	
Strongly Disagree						Strongly Agree

17. In new product development, we avoid designs that require dimensional changes of existing manufacturing process. *

	1	2	3	4	5	
Strongly Disagree						Strongly Agree

18. In new product development, we avoid designs that require high cost of manufacturing in existing manufacturing process. *

	1	2	3	4	5	
Strongly Disagree						Strongly Agree

19. In new product development, we avoid designs that require longer time for manufacturing in existing manufacturing process. *

	1	2	3	4	5	
Strongly Disagree						Strongly Agree

20. We emphasizes on shop-floor employees' involvement in product development. *

	1	2	3	4	5	
Strongly Disagree						Strongly Agree

21. We emphasizes on cross-functional workforce / cross-functional work teams. *

	1	2	3	4	5	
Strongly Disagree						Strongly Agree

22. We emphasizes on cross-functional training of employees. *

	1	2	3	4	5	
Strongly Disagree						Strongly Agree

23. We emphasizes on job rotation of employees. *

	1	2	3	4	5	
Strongly Disagree						Strongly Agree

24. We emphasizes on job training / job training programs. *

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

Questionnaire Part Two: Research and New Product Development

1. We emphasize on changing product architecture* through modifying the ways in which core components* are linked together (the core components* may be reinforced if needed) *

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

2. We emphasize on changing product architecture* through modifying the ways in which core concepts* are linked together (the core concepts* may be reinforced if needed) *

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

3. We are developing new knowledge about the possible linkages* among the core components* of our product. *

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

4. We are developing new knowledge about the possible linkages* among the core concepts* of our product. *

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

5. We allocate enough resources to support ideas regarding new product architectures*. *

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

6. We encourage interactions among different departments in the organization for product development. *

1 2 3 4 5

Strongly Disagree ○ ○ ○ ○ ○ Strongly Agree

7. Our company is flexible to allow experiments on re-organizing the existing components for new product architecture* (the components may be reinforced if needed). *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

8. Top management is committed to new ideas of re-organizing the existing components of product to create new product architecture*. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

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100%: You made it.

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