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McGill University

Department of Mechanical Engineering

MECH 497 - Value Engineering

Redesign of the Axis SOLEIL Pendant Luminaire

Final Report

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EXECUTIVE SUMMARY

This project addresses conversion of a popular Axis ceiling fixture line from fluorescent to LED lighting. [Maybe some of the blurb below could be reduced.]

Altering light in an enclosed space not only changes the environment's appearance, but its ambiance. For example, bright, white lights promote productivity and increase attentiveness while warmer and darker light tones have less impact on circadian rhythms and are used during the evening [1]. The client, Axis Lighting Inc., uses patented LED Surround Lite to completely illuminate a space, including corners normally hidden in shadow. However, one of their older light fixtures, the SOLEIL luminaire, still uses fluorescent tubes. This report details the redesign of their current SOLEIL luminaire fixture to incorporate LED Surround Lite technology and increase value associated with the new design proposal by applying value engineering methodology. For more detailed analysis and specific calculations behind the report's assertions, please see the Appendix where applicable.

The redesign includes updating all the mechanical components to support the LED Surround Lite technology while maintaining the specific design aesthetic created by Axis Lighting Inc. Furthermore, components should be manufactured using Axis' existing processes (sheet metal forming, die-casting, and extrusion) to decrease component cost. Following the value engineering job plan – gathering information, analyzing the functionality and preliminary cost of the existing fixture, brainstorming and evaluating design ideas, and developing value proposals– we recommend the updated design with the highest value added to our client.

The proposal focuses on the four primary functions of the light fixture: (1) Look appealing; (2) Incorporate the new technology; (3) Facilitate service; and (4) Adapt to user needs and preferences. By keeping the outer appearance of the light fixture provided by Axis and implementing LED panels, light guides, and a programmable power supply (i.e. driver), the first two main functions are fulfilled. For the light fixture to be easily serviced and to adapt to user needs, the design incorporates an access port for the driver and a customizable, removable cartridge which houses the optical lighting components.

The recommended solution consists of three cartridges containing the LED panels and light guides which snap into an extruded main housing. The driver sits within the main housing and can be accessed from the top via an extruded panel that swings open and snaps shut. Die-cast joiners allow for the fixtures to be attached to one another. While this proposed design is more expensive than the current fluorescent bulb fixture, this is due to the cost of the LED technology. The benefits of this technology as well as the easy-to-service design make the recommended proposal more valuable to Axis Lighting Inc. as well as to the client.

... due to the current cost of LED technology, a cost which will greatly decrease as demand grows and manufacture becomes more efficient driven both by production volume & technique improvement.

ACKNOWLEDGEMENTS

We, the undergraduate value engineering team from McGill, would like to express our gratitude towards Ms. Jennifer Abboud, jr. eng. at Axis Lighting. She has invested a valuable amount of time in this project to make sure we were knowledgeable enough to bring value to this product.

We would also like to thank Ms. Lucie Parrot, eng., M. eng., CVS, Professor Vince Thomson, and Professor Paul Zsombor-Murray for introducing us to value engineering methodology, an unusually valuable engineering tool.

Finally, we thank McGill and Axis Lighting for giving us the opportunity to apply our engineering knowledge to a real engineering challenge. The knowledge acquired in this design process will be a career asset.

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CONTEXT AND OBJECT OF STUDY

VALUE ENGINEERING

The goal of the Value Engineering methodology is to maximize the value of the product. Value is defined as the ratio of satisfaction of the needs of the customer to the cost of the product. Thus, in order to increase the value of a product, it is important to understand what those needs are to formulate a design that satisfies those needs while remaining cost competitive.

CLIENT

Founded in 1991, Axis Lighting has become a well-known name across North America for producing customizable architectural lighting, with an emphasis on energy efficiency and high performance. As we learned from our review of the market, a great light fixture is one that does not draw attention to itself; the design of the fixture, as well as the light distribution, need to be seamlessly integrated into the working space.

INITIAL DESIGN

The project presented to our team consists of redesigning the internal structure to update an Axis product. The goal of the redesign is to integrate LED technology into the SOLEIL pendant luminaire, while abiding by the requirements, specifications and constraints provided by the company. Updating the technology brings the SOLEIL into the company's LED product line to improve the product both as a lighting system and in terms of satisfying its users.

A thorough review of Axis's product line was done to see how this product could fit in with their current portfolio. By incorporating their existing innovative ideas and our design recommendations we seek to maximise the value of the light fixture without duplicating other Axis products.

Figure 1: Old Axis SOLEIL Pendant Luminaire

VALUE ADDITION

As LED lighting technology is inherently more expensive than fluorescent bulbs, we expect a marginal increase in the cost of the final product. However, we aim to compensate for this increase in cost by greatly increasing the satisfaction of the customer – this is the primary focus of this value engineering study.

On a basic level, our task of updating the luminaire to include LED technology will by default increase its value – LED technology is more robust and energy efficient than fluorescent bulbs, and the principal increase in the value of the light fixture will come from this new technology. In this project, the value engineering methodology is used not to confirm what we already know – that LED technology will add to the value of the fixture – but to find ways of further increasing value in ways not immediately obvious. The value engineering methodology provides an excellent framework for incrementally increasing the value of all aspects of a product. This is done first by understanding in detail the specific functions of the product, and then by how to properly achieve these functions at the lowest cost.

Although the new product is based on an existing fixture, its updated form and technology make it quite different from the original design and we will refer to the old design only as a reference as, for all intents and purposes, we are creating a new fixture. As a basis, our team was provided with a shell of the new luminaire created by the lead industrial designer at Axis. Our team’s task consists of coming up with the mechanical design of the fixture to make its aesthetic possible; that is, how to house the internal circuitry, LEDs and optics while maintaining the form and geometry of the outer shell. Furthermore, we were given a number of specimen components to be integrated: the LED boards, light guides, LED drivers, and wire hangers. Further details on constraints will be outlined in the information section of the report.

OBJECTIVES

The value engineering services of the team were sought to develop and conceptualize a CAD model of a redesigned architectural light fixture based on a provided look/aesthetic of its outer shell while increasing the product value at all stages of the design process

The scope of this study does not include decreasing manufacturing costs through analysis of various suppliers and manufacturers, nor decreasing assembly cost through an analysis of the Axis assembly line – the team will rely on Axis for our cost estimates. The team will attempt to minimize cost throughout this study by reducing the number and complexity of parts, and increasing the ease of assembly.

TEAM MEMBERS

The value engineering team members are all from the Department of Mechanical Engineering, and work under the supervision of a company representative from Axis Lighting; their names and roles are outlined in Table 1 below.

Table 1: Value Engineering Team

Member	Role
Jennifer Abboud	Axis Lighting company representative
Riel Bessai	Team member
Carl Laverdiere	Team member
Gabrielle Robert	Team member
Maxence Scully	Team member
Sterling Shaner	Team member
Samantha Yung	Team member

Figure 2: Value Engineering Team Members

From Left to Right: Jennifer Abboud, Riel Bessai, Maxence Scully, Carl Laverdiere, Sterling Shaner, Samantha Yung, Gabrielle Robert

METHODOLOGY

The value engineering process is a systematic methodology used to optimize the value of a product; to ensure the satisfaction of the client's needs at the lowest possible cost. The stages of a value engineering workshop are as follows:

- Organisation phase
- Information phase
- Function and Cost Analysis
- Creativity phase
- Evaluation phase
- Development phase

The organisation phase was the first step of the process and consisted of analyzing the current situation and determining the purpose and objectives of the value engineering workshop. The information phase was where information about the product was gathered. The function and cost analysis phase consisted of breaking down the product into specific base functions and determining the cost of performing each of these functions. The fourth phase was the creativity phase, where multiple solutions for each function were generated; in our case, these solutions mainly consisted of alternative design ideas. The fifth phase was the evaluation phase, where the various concepts generated in the creativity phase were analyzed for their merit. In this section, we focused on the best concepts to be included in the final design. In the development phase we generated value proposals which consist of specific recommendations on how to increase the final value of the fixture. Finally, we demonstrated the feasibility of these proposals by embodying them in a detailed design.

In this section the specific techniques that our team used in each phase of the value engineering workshop are presented. The results of each of these phases are also presented, from which concrete value proposals were generated aimed at increasing the value of the redesigned product. These proposals are detailed in the Appendix of the report, along with tables and charts developed in each of the following phases.

INFORMATION PHASE

The purpose of the information phase is to gather maximal information on the product that is to be redesigned. The bulk of this information was provided by the Axis company representative, Jennifer Abboud.

The team was first presented with information about our client, Axis Lighting, as well as general information pertaining to the lighting industry. As none of the team members are experts on the subject, it was crucial for each member of the team to learn about the fundamentals of architectural lighting. To further understand architectural lighting, the team attended a talk sponsored by Axis Lighting, given by Nelson Jenkins, an expert in the field of lighting design, working with Lumen Architecture. This presentation was valuable as it demonstrated the numerous uses and benefits a lighting fixture could provide to a space, giving insight as to how the target fixture could play a role. Axis Lighting often works with lighting designers with their engineering team on hand to redesign their stock fixtures for custom projects. As such, the existing fixtures can be seen as a blank canvas from which new customized designs are created. This was important to note, as the redesign will not only serve as a stock fixture, but something that will be largely modular and customizable for the client.

As this VE study is aimed at redesigning a light fixture, we were presented with detailed CAD drawings of the existing SOLEIL luminaire pendant, which we were given the task of updating with LED technology. Details of the existing design are presented in Appendix A-2. The team was also presented with a shell of the new concept design created by the Axis lead industrial designer. This shell, pictured in Figure 3, is the main constraint of the redesign, as the new technology must be incorporated into the new luminaire such that no changes are made to the appearance of the shell provided.

Figure 3: Shell of Updated SOLEIL Pendant Luminaire

Many of Axis' light fixtures are designed for row configuration, including the SOLEIL luminaire. The fixtures are designed as four-foot units, but include provisions such that multiple units can be connected in series. Each four-foot unit can either be connected to another unit using a connector, or can be fitted with an end cap. This flexibility is the backbone of an architectural lighting fixture, as it allows for a single design to be used in a wide range of spaces. It was imperative that the new design allow for row configuration, and that individual unit length was maintained at four feet so as to be mounted to a standard grid ceiling.

The new fixture will incorporate LED technology. A major constraint of this redesign was therefore the incorporation of the LED boards (the actual lights), the LED drivers which power the boards, and the light guides. The patented light guides are thin, extended pieces of material, which use molecular optics to guide and diffuse the light produced by the LED's [2]. These three components comprise what we will refer to as the "optics" of the new light fixture. In the new fixture, there are to be three light guides per four-foot section. These light guides are illuminated from the sides, and act to diffuse the harsh LED light.

The new fixture will use aircraft cable to hang from the ceiling. The end of this cable is attached to a small solid cylinder, which slides in a channel along the length of the fixture, allowing the fixture to accommodate different mounting configurations based on the ceiling type.

Many other Axis Lighting fixtures employ this method of suspension, and the new design must include this channel.

Axis uses similar manufacturing processes for all of its lighting fixtures. Another constraint is to design components that can be readily manufactured by Axis' existing suppliers. Extrusions are used to construct almost all components that run the length of the fixture. A major complaint from Axis Lighting in regards to the current SOLEIL luminaire is the quantity of parts in the design. Some of their more current models smartly make use of the main housing extrusion for the majority of necessary functions. Accordingly, the team aimed to use this technique to reduce the number of parts and assembly time to decrease the cost of the lighting fixture. Other manufacturing processes that Axis has access to are sheet metal forming, and aluminum die-casting for the end-caps. Post-manufacturing machining was to be avoided when possible as it is costly and has to be done in-house.

Axis assembles their fixtures in house, with manufacturing mostly being outsourced. There are two assembly teams, one electrical team and one mechanical team. These details were important for the later stages when attempting to reduce costs through manufacturing and assembly.

FUNCTION ANALYSIS PHASE

The function analysis phase is aimed at determining in specific detail what the functions of a product are. The most general function of a light fixture is to illuminate space. However, it also has the functions of hanging from the ceiling and looking aesthetically appealing. During this phase the team used various methods to unearth the more specific functions of a light fixture that may not be obvious at first. These functions were then organised in a functional diagram, where more abstract ideas lead to more specific functions by asking the question "How is this function accomplished?" This functional diagram is included in Appendix A-5 and A-6 Once the most basic functions that must be accomplished by our product were understood, they were then rated in order of importance to the client. To create a basis, the previous SOLEIL luminaire was used as an example to determine how much of the product's cost was spent on what functions to measure how resources were allocated according to functional importance. This allowed the team to generate designs which, above all, allocated resources according to this functional importance, efficiently maximizing the value of a product.

In using functional analysis, functions of a product or process must be described by an active verb and a measurable noun. Using these two words to describe the function allows for the simplification of the problem and ensures that the problem is well understood. To begin, intuitive research was used to generate a list, presented in Appendix A-1, of basic, secondary and constraint functions pertaining to the fixture. A basic function describes what the product is expected to do or how it serves to accomplish the goal of the product. The support or secondary function may be necessary to describe a designer need rather than a user's or it serves as an action which "supports the accomplishment of the basic function." Lastly, the constraint functions are the limitations the product must abide by. The purpose of starting with this method to determine the functions of the fixture was to get a better grasp of the overall product and its functions.

Another method that was utilized in this phase was reference product analysis, which allows functions to be found by decomposing similar or competitive products into their various elements and determining their function. For the LED fixture, the reference was conducted based off the fluorescent version of the Axis SOLEIL pendant. This analysis can be found in Appendix A-2.

Environmental analysis was also used to develop the functions of the LED fixture and is presented in Appendix A-3. With this method, functions are found by describing what the product must do when interacting with its surroundings. This method was particularly important, as a constraint provided by Axis was that the light fixture had to accommodate various spaces depending on customer needs.

Once the functions were listed, they were then organized and prioritized into various functional groups to generate a FAST diagram, which allows the functions to be organized sequentially until a solution can be generated. This allowed the functions generated by the preceding methods to be narrowed down and for common functions to be found which also served as an indication of the importance of the function.

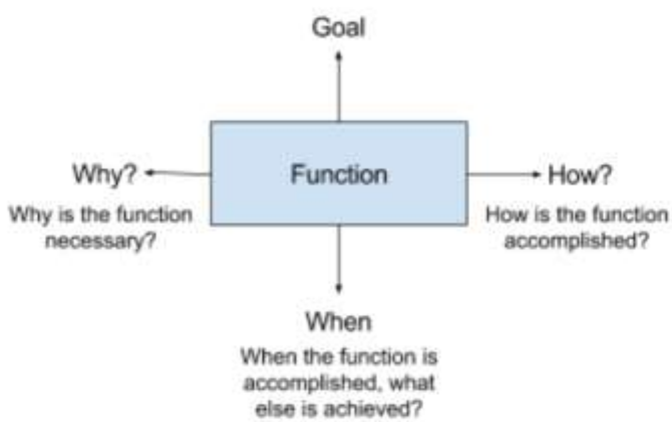


Figure 4: Functional Analysis Diagram

Figure 4 depicts how each function was analyzed and categorized. The functions were organized using the Classical FAST model, where each function was analyzed by asking “Why is the function necessary?” and “How is the function accomplished?” This is known as the HOW-WHY logic. Moving from left to right on the diagram explains how a function is performed, while going from right to left describes why the function is accomplished. A hierarchy function model was also integrated into the diagram by vertically listing the functions by their importance.

To begin the process of building the diagram, it was first important to determine what the goal of creating the fixture was. The primary function of the product was to illuminate space, but it was equally as important for the light to attract buyers, from a business perspective. Thus, the goal of the product was to attract buyers but the mission statement, which the functions branch from, was to illuminate space with new technology adapted to the existing fixture, while maintaining and improving commercial success. This was selected as it encapsulated the requirements established by Axis and addressed both the needs of the customers purchasing the fixture and our client.

When asking how the mission statement would be accomplished, the solution was to update the fixture. However, after much discussion, it was decided that this did not fully address the question from the perspective of the light. It was implied that the fixture had to be updated, as this was the purpose of the project presented to the team by Axis. To rectify this, “update the fixture” was changed to “take over catalogue spot of current fixture.” Through the process of building the functional diagram, various changes were made to ensure that the flow of the diagram was logical and that the functions addressed the initial goal and allowed for a solution to be found. Functions were also modified to be made more concise and repetitions were removed. For example, the in the early version of the diagram in response, when asking how to “facilitate service”, the solution was for the fixture to be “built from standardized parts.” However, after further discussing and looking over the diagram as a whole, it was noted that standardizing the parts of the fixture better served another function. As a result, this function was added as a solution to adapting to user needs.

From the beginning, emphasis was made on ensuring that the fixture was customizable based on customer needs. To allow for customization, it was therefore important that the fixture be built using a standardized process, and therefore using standardized parts. Doing so would provide Axis with the ability to modify the fixtures for their clients without having to create an extensive amount of new parts. Another change that was made between the first and final diagram was the placement of the ability of the fixture to allow for a specific light distribution. Originally, the function, “Achieve uniform light distribution” was placed so as to respond to “Encapsulate electronics.” After a review of the logic of the diagram, it was evident that “Achieve uniform light distribution” did not provide a solution to the question “How is encapsulating the electronics accomplished?” As a result, the function was moved further down the tree as a solution to addressing the needs of the user. It was deemed more appropriate as the purpose of allowing for different light distributions was a key Axis feature designed specifically in their products to allow their clients to choose their desired light distribution based on where the fixture would be located and for what purpose the fixture would serve. The final functional diagram is presented in Appendix A-6, along with the earlier version of the diagram in Appendix A-5.

After completing the final diagram, the functions were characterized based on their criteria, level, flexibility and ranking, which are described below.

- Criteria: describes how each individual function is achieved and measured
- Level: indicates what is acceptable for each criteria
- Flexibility: specifies how much deviation can occur for the level specified
- Ranking: importance of the function to the product

Each function was looked at individually and verified by Jennifer to ensure that the company was satisfied. For our product, the aesthetic, the housing of the optics and the ability to uniformly distribute light were amongst the functions of greatest importance so as to comply with Axis standards. The table of characterized functions can be found in Appendix A-7.

COST ANALYSIS PHASE

After performing the required functional analysis to obtain a better picture of the product, the team quantified each function in terms of cost. The cost of components of the previous SOLEIL fixture was provided by the client, providing a reference to start with. From this, the team broke down all the components, based on the reference analysis product table, to quantify the weight of the cost of each component that goes towards realizing that function.

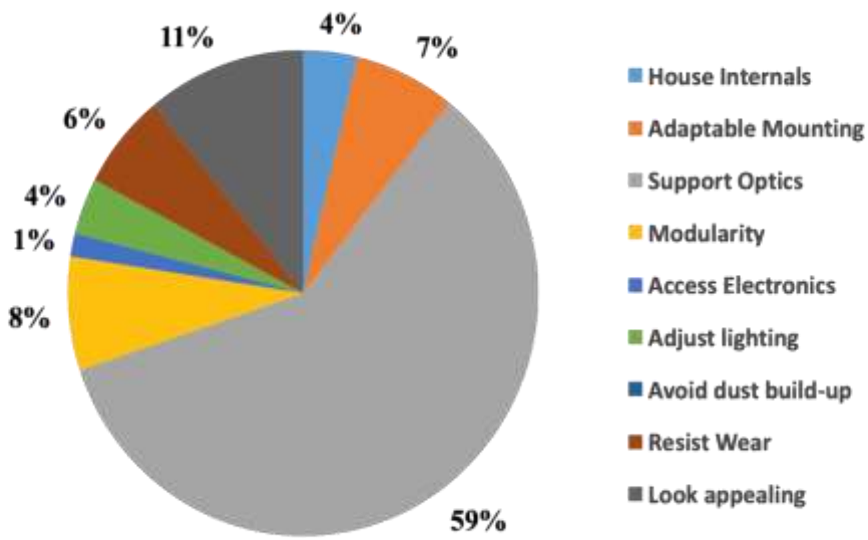


Figure 5: Cost Analysis of Old SOLEIL Fixture

From this analysis, shown above in Figure 5, it was determined that about 60% of the cost from the old design came from the function “support optics”, in other words, implementing lighting technology. Because this function is at the core of the product, there is not much the value engineering team can do about optimizing this parameter. Based on this information, the value engineering team decided to bring value to the new SOLEIL fixture through a design prioritising ease of assembly and service. By optimizing the assembly, the ease of maintenance and the serviceability of the product, the team will be able to create more value (satisfaction of the needs) for a similar cost.

CREATIVITY PHASE

After understanding the intrinsic details of the product, the team began characterizing the different functions required of the fixture; for this it was important to take a step back and see the product from a wider perspective. Before the creativity phase, each member of the team took time and thought about different ways to achieve the required functions. Once these functions were listed out, the team began to develop solutions to the functions through several whiteboard brainstorming meetings. This visual method helped organize our thoughts, as well as generating new ideas from concepts explored by other member of the team.

Because the design will use the same material and manufacturing methods as the other fixtures in the Axis Lighting portfolio, cost was not the main focus of the brainstorm, but rather how to improve the profit margin on the product by using parts for additional functions. After computing the cost per function (see section above), the team realized the best way to increase the value for this product was to ease serviceability and assembly of the fixture; this was emphasized throughout the creativity session.

During several sessions our company representative was not present. This was beneficial as it helped free more creative designs, as team members were not shy of sharing any ideas that may seems ridiculous at first. This openness of sharing made creativity sessions much more productive in terms of concept generation, as well as the feedback from our advisor which directed our ideas further.

EVALUATION PHASE

Based on the creativity table generated in the previous section, we had a broad spectrum of ideas of various levels of feasibility. Our next mission was to reduce the number of concepts down to those that were most feasible. Numerous tools could be use to evaluate the validity of concept, from Pugh Matrices to a House of Quality; however, as most concepts were generated without the presence of our company representative, we decided to use a gut feeling index. This tool is fairly quick to use and encouraged lively discussion within the team.

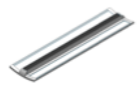
The gut feeling index was used to sort out the different ideas/concept to help focus on the one that are the most important. A round-table discussion was held for every concept and their validity and usefulness was graded out of ten. Ms. Abboud helped discard some ideas that seemed promising at first and think about concepts that were overlooked. The Gut feeling index can be found in Appendix A-8.

DEVELOPMENT PHASE

As discussed above, the conclusion of the evaluation phase left our team with several key points of the design which all had valid and attractive alternatives. The evaluation phase focused attention towards key aspects of the design in which value could be increased. The main topics of contention were concerning the packaging of the light guide and LED boards, joining and end caps, access to the driver, and ways to hold the assembly together.

To organize the ideas developed, a morphological chart, as seen in Table 2 was created to address some of the key functions of the LED fixture. By creating this chart, the team was able to visualize and get an overview of the different proposed features. Upon discussion between the team and with consultation with our company representative, our final choices for the fixture were selected and are discussed below.

Table 2: Morphological Chart

Function \ Solution	1	2	3	4
Respect Axis design				
Permit adaptable mounting	Slots for cables	Deeper channel		
Support optics	3 identical cartridges	No cartridge	1 cartridge	3 separate cartridges
Allow access to optics/electronics	No cartridge	Sides: Top Center: Bottom	Sides: Bottom Center: Bottom	
Incorporate LED Technology	Center: 2 LED Sides: 2 LED	Center: 2 LED Sides: 1 LED, 1 Mirror	Center: 2 LED Sides: 1 LED, 1 Reflector	
Allow access to driver	Snapping mechanism 	Snapping mechanism 	Push & slide 	Plate & 4 screws 
Attach end caps	End bracket plate	Press fit with pins	Cap with hollows	Pins to snap
Allow light row configuration	End plate with male/female parts	Extensions on rails	End plate with pins	
Use light shield attachments	Snap into extrusion	Snap into cartridge	Slide into extrusion	

PACKAGING OF THE LIGHTGUIDE AND LED BOARDS

To fulfill our function of serviceability, the method of accessing and replacing the LED boards was raised. As the optics required a snug fitting of the LEDs and the light guide, it was apparent that the LED boards could not be separated from the fixture without the light guide; the two choices the team decided on were to pack the two in a removable cartridge or to make them individually removed from within the housing. The removability of the LED boards was emphasized by our company representative as LEDs often require premature replacement for such occasions as customisation of light and power surges. In fact, as little as two failed LEDs would be noticeable inside a board. Accordingly fulfilling the function of ease of maintenance was extended to the LED boards as well as the driver.

Convinced of the value of cartridges, the options were thus the number and direction of access. In order of preference, our top three alternatives were: three separate cartridges, accessed from the bottom in the middle and the top on the sides; three cartridges, all accessed from the bottom; and one cartridge, installed from the bottom. The last option was discarded on the reasoning that although it would reduce the number of parts, if one LED board were to fail, the entire cartridge would need to be replaced. The benefits of the first option was that it would minimise the number of visible fasteners, as the top is generally unseen, thus increasing the visual attractiveness of the light fixture, and thus the value.

Upon discussion, the team selected a three cartridge design, with access from the bottom in the middle and the top on the sides. This would increase the attractiveness by reducing the number of possible visible fasteners. Planning for both ease of manufacturing and assembly, members of the team agreed that this design could use identical cartridges to minimise parts and utilise snap designs made possible by extrusion.

JOINING METHODS AND END CAPS

The next area of contention was the design of the joining methods for row configurations and the endcaps. Initial concerns were raised about the level of machining tolerance required for a flush mating of end caps and fixtures. Alternative options were: a flush seam, bracketed from the inside with a bolt; a semi-overlap, where joining parts would only overlap an end plate; and an overlap, where joining pieces would fully cap the light fixture, as a hat would on a head.

Our decision on this matter was heavily clarified, however, by a tour of the Axis Lighting facility where the team was able to see existing lighting models. During this tour we all agreed that a flush design was indeed possible with negligible increase of costs. Therefore, our final proposal would pursue such an option as to increase the attractiveness of the light, and thus its value.

DRIVER ACCESS

The driver is what powers the LED boards and allows the light to be dimmed. Accessing the driver is imperative for maintenance purposes as it is the component which fails most frequently. The location of the driver access port was constrained by the shell design provided by Axis. Their design included a top-access area for bulky electronics in the centre of the fixture. Top access would also hide all proposed hinges, doors, and fasteners from the user, ensuring an attractive and seamless appearance. Although the access port location was agreed upon, the method of accessibility was to be determined.

One popular vein of designs centralised around the common television remote or cordless mouse, illustrated below in Figure 6. These designs were attractive to the team as they promised very flush designs.

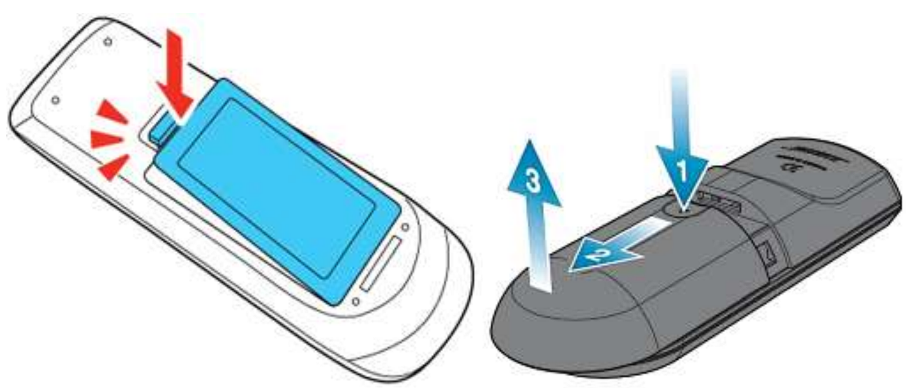


Figure 6: Snap Design (Left) and Push-and-Snap (right) on a Television Remote

Another design alternative was to harness the capabilities of extruded parts and include latches that snap to close the access cover for the housing. An example of snap is show below in Figure 7. Simpler options included a plate held in place by four screws, a hinge, or a sliding door.

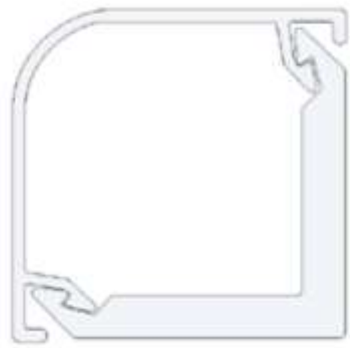


Figure 7: Example of Snap Joining of Extrusions by SAPA Group

The final consensus of the team was to include a snap feature in the extruded parts of the housing. Although more complex extrusions would be required with better tolerance, thus increasing the price of the extrusion die, the elimination of extra screws and parts was seen as more valuable. Additionally, eliminating visible fasteners and a flush cover would increase the attractiveness of the fixture and mesh more closely with the existing portfolio of Axis Lighting's fixtures.

STRUCTURAL PLATES

The consensus on structural plates was in comparison much higher. For the fixture to be rigid, the extrusions needed to be held together tightly. Furthermore, edges must be entirely in line along fixtures such that the cables suspending the fixtures could be slid from fixture to fixture; distortions and waviness in the extruded parts due to differences in cooling rates would doubtlessly ruin specified tolerances. Various ideas included using a cast or sheet metal part with screw ports and or divots to properly locate the extrusions within the fixture, and link them together in a flush manner when in rows. Similar plates would be required for the cartridges.

Upon review of existing light fixtures at the Axis facility and learning of complaints and performance of their past and present designs, our team decided to use a cast end plate to locate the parts of the housing by means of divots and screw channels.

CONCEPT SELECTION

To be able to quantify the value of the different designs the team used a merit table and value graph. These two tools help to give the client an objective assessment of each design and to determine which proposal should be implemented. With the help of our company representative, evaluation criteria were listed in order of importance. They are explained in more details below. A weight was also assigned to each criteria and, as a group, each design was evaluated in the most objective way possible. The results can be found in Table 3.

NEW TECHNOLOGIES

The goal of this project was update the SOLEIL light fixture with LED board. This new way of emitting light as many advantages, as described previously in this report. It is the most important criteria as this is the main purpose of this value engineering study.

LOOK APPEALING

Axis Lighting makes custom light fixtures that are aesthetically appealing and that integrate seamlessly with a building’s architecture. Therefore, it was important to respect their aesthetic shell design, while integrating LED technology.

FACILITATE SERVICEABILITY

Because the initial cost of the fixture is constrained by the inclusion of the LED technology, it was imperative to lower the operational cost of the product. This was primarily done by facilitating the maintenance and serviceability of the light fixture.

ADAPT TO USER NEEDS

By providing a modular design that is flexible and customizable, it is easier for Axis Lighting to accommodate the different needs of the client in terms of space constraints and length of the light fixture.

POWER CONSUMPTION

When used on a commercial scale in large buildings, lower power consumption can represent considerable operational savings. Therefore, it was considered an important selling criteria for potential customers.

SUSTAINABILITY

Knowing that the products they are purchasing are environmentally friendly can provide a selling point to new customers. The fixture can also provide substantial benefits to developers in terms of sustainability tax rebates.

EASE OF UPGRADE

Technology is constantly evolving. The ability for customers to upgrade their lighting solutions without having to completely retrofit a building with brand-new fixtures was considered beneficial.

Table 3: Merit Table

Criteria	Weight	old	new	no cartrige
New technologies	10	1	10	10
Look appealing	8	5	10	10
Facilitate service	9	6	10	4
Adapt to user need	9	4	10	7
Power Consumption	7	2	10	10
Sustainability	8	0	10	10
Ease of Upgrade	8	1	10	1
total		162	590	437
total Cost		$ 108.11	$ 299.49	$ 285.00

Each design was evaluated with respect to each of the aforementioned criteria. The results of these evaluations can be seen in the merit table above. The value of each design is quantitatively specified by the total satisfaction of user needs divided by the total cost. In order to better visualize the value in each case, these value proposals are plotted on a graph, as seen in Figure 8. The y-axis represents the satisfaction of user needs, and the x-axis is the cost of the design. As such, the value is represented by the slope of each proposal: the one with the steepest slope has the highest value.

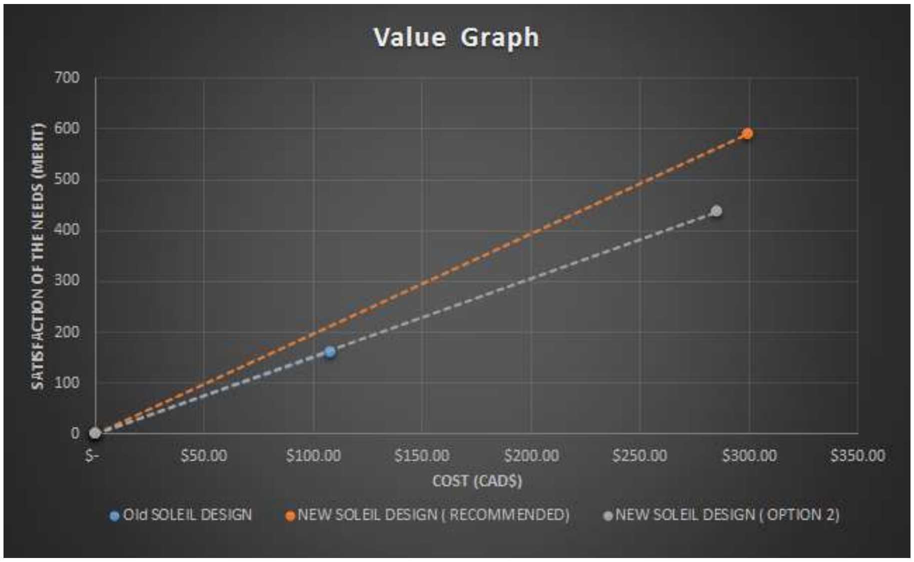


Figure 8: Value Graph Comparing Old Design and New Proposals

From this, it can bee seen that the old SOLEIL design provides similar value to the new SOLEIL design without any cartridges. However, the recommended solution with cartridge provides more value than the two other designs, despite its increase in cost.

PROPOSALS

From the development phase, a number of conceptual solutions were expanded upon to determine viability. The best of these solutions are embodied in two design proposals. In applying the value engineering methodology to this project, it should be noted that there were several constraints that had to be considered for the design of the final product. The appearance of the shell very much defines the fixture: it was designed with just enough space to house the LED boards, light guides, and drivers, with little leeway. The Axis industrial designer clearly had an idea of how the fixture would house each of these components; thus the task at hand was to determine the specifications of this ensemble. Some conceptual solutions were clearly preferable from the start, while others were vetoed directly by the company representative. As such, it was difficult to generate multiple proposals with a large variability between solutions. For this reason two proposals are presented that are somewhat similar in nature.

Many of the ideas outlined in the creativity section were previously analyzed for their merit. Some solutions were clearly better than others. As such, both of the proposals employ the same solutions to most functions. For example, each proposal utilizes a snap door to access the driver, although a number of other solutions were previously discussed.

The main discussion during the design process was whether the optics – the LED boards, and light guides – should be housed in a removable cartridge or not. This cartridge would allow easy access to the electronics, and would be easily replaceable should the LED boards fail and require replacement. The two proposals revolve around this discussion. Having a cartridge based design has its benefits and drawbacks. It requires additional parts to be manufactured in order to house the optical components, increasing the overall cost of the fixture. On the other hand, it allows the LED boards to be accessed and changed without the need to disassemble the entire fixture. This is important for ease of use and serviceability. The discussion between these two proposals is one of cost versus quality. As either method of embodying the optics has its merit, both solutions will be proposed to Axis Lighting in regards to the SOLEIL Pendant Luminaire.

Because of the constrained nature of this project, in applying the value engineering methodology it was concluded that the principal way to increase the overall value of the fixture was to streamline manufacturing, assembly, installation, and serviceability. This was done in order to reduce overall costs and improve customer satisfaction. The reduction of manufacturing costs, as well as the ease of interaction between the users (incl. shop workers, installation personnel, etc.) and the fixture in regards these categories determined by and large the final proposed design.

In this section, each proposal is outlined in detail. The value engineering team recommends the cartridge proposal over the no-cartridge proposal, and that decision is then justified. Finally, the proof-of-concept design is presented to Axis Lighting. Value was increased throughout the design process, and in many ways these increases can only be seen in the details. As such, they are outlined as well.

PROPOSAL 1

Using the morphological chart in Table 2, the first proposal was generated by making a selection for each of the functions listed in the chart. This proposal houses the optical components – the LED boards, light guides and reflectors - directly in the main extrusion, and does not make use of the cartridge described previously. Table 4 depicts the components that were selected for the first proposal. It includes a sliding slot for the mounting cable in the side-rail, and a snapping door to access the driver from above.

This proposal places an emphasis on cost-reduction at the expense of serviceability. The lack of cartridge means less parts overall, but should a LED board need to be changed, the entire fixture would need to be disassembled. This is especially problematic when configured in row assembly, where the fixture would need to be disconnected from the row, the LED board changed, and the fixture reconnected. However, the LED boards are quite robust and have a life expectancy of about 10 years.

Table 4: Proposal 1

Function \ Solution	1	2	3	4
Respect Axis design				
Permit adaptable mounting	Slots for cables	Deeper channel		
Support optics	3 identical cartridges	No cartridge	1 cartridge	3 separate cartridges
Allow access to optics/electronics	No cartridge	Sides: Top Center: Bottom	Sides: Bottom Center: Bottom	
Incorporate LED Technology	Center: 2 LED Sides: 2 LED	Center: 2 LED Sides: 1 LED, 1 Mirror	Center: 2 LED Sides: 1 LED, 1 Reflector	
Allow access to driver	Snapping mechanism 	Snapping mechanism 	Push & slide 	Plate & 4 screws 
Attach end caps	End bracket plate	Press fit with pins	Cap with hollows	Pins to snap
Allow light row configuration	End plate with male/female parts	Extensions on rails	End plate with pins	
Use light shield attachments	Snap into extrusion	Snap into cartridge	Slide into extrusion	

PROPOSAL 2

For the second proposal, many of the components selected from the morphological chart in proposal 1 were kept for proposal 2 – with the exception being how the optics and electronics are supported and accessed. This proposal divides the fixture into electrical and mechanical subassemblies. The electrical subassembly consists of all the optics – the LED boards, light guides, and reflectors – housed in a cartridge. This cartridge is removable so as to access the LED boards should the need for replacement arise. Its design is also universal in that the same cartridge can be used for the sides as well as the middle (three in total). This design will be more expensive than proposal 1 as it includes extra components, but improves value through ease of installation and maintenance. Table 5 depicts the other features that are to be included in proposal 2.

Table 5: Proposal 2

Function \ Solution	1	2	3	4
Respect Axis design				
Permit adaptable mounting	Slots for cables	Deeper channel		
Support optics	3 identical cartridges	No cartridge	1 cartridge	3 separate cartridges
Allow access to optics/electronics	No cartridge	Sides: Top Center: Bottom	Sides: Bottom Center: Bottom	
Incorporate LED Technology	Center: 2 LED Sides: 2 LED	Center: 2 LED Sides: 1 LED, 1 Mirror	Center: 2 LED Sides: 1 LED, 1 Reflector	
Allow access to driver	Snapping mechanism 	Snapping mechanism 	Push & slide 	Plate & 4 screws 
Attach end caps	End bracket plate	Press fit with pins	Cap with hollows	Pins to snap
Allow light row configuration	End plate with male/female parts	Extensions on rails	End plate with pins	
Use light shield attachments	Snap into extrusion	Snap into cartridge	Slide into extrusion	

PROPOSAL SELECTION

Upon discussing with the Axis company representative, she expressed an inclination towards the cartridge based design, and emphasized Axis' desire to allow the fixture to be serviced without disassembly. As such, proposal 2 was recommended to Axis Lighting.

Although using cartridges requires additional parts, they add considerable value to the fixture. Using cartridges facilitates maintenance, and simplifies the servicing of the fixture. For example, should a LED board need to be replaced it would simply require popping out the cartridge from the fixture and inserting a new cartridge. This not only makes for ease-of-use, but improves the lifecycle cost of the product. These cartridges also allow for the assembly to be divided into electrical and mechanical subassemblies, improving efficiency on the shop floor. Additionally, when considering future use, these removable cartridges can be easily updated with newer technology.

DESIGN RECOMMENDATION AND PROOF-OF-CONCEPT

In order to demonstrate the feasibility of the recommended proposal, a detailed mechanical design of the fixture was generated. This design is closely based on shell provided by Axis Lighting. The final design can be seen in Figure 9. It is composed of a frame which maintains the form and aesthetic geometry of the fixture and holds the drivers, while the optics are housed in three removable cartridges. The fixture is designed in approximate four-foot sections, but accommodates row assembly. This means that as many four-foot sections as desired can be joined together to create a long, uniform pendant fixture.

Figure 9: Recommended Design with soda can for size comparison

As outlined previously, value was considered throughout the design by streamlining the manufacturing, assembly, installation, and maintenance processes. Within the mechanical design many show how value can be increased with minimal design modifications. For example, screw channels are built into the extrusions directly in order to use self-tapping fasteners rather than post-machining tapped holes. This can be seen in Figure 10. First, value added is demonstrated across each of these categories, followed by a detailed explanation of the fixture's design.

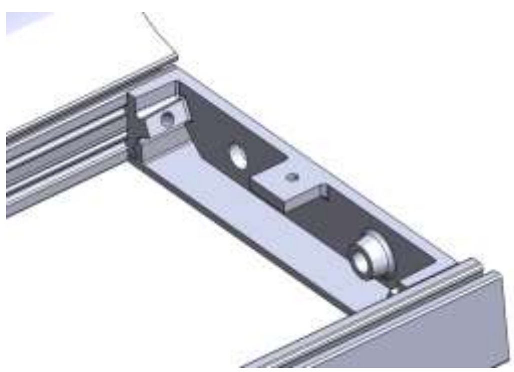


Figure 10: Joiner Screw Channel

MANUFACTURING

Axis primarily uses extrusions in their lighting fixtures, with die-cast parts used otherwise. Manufacturing costs were decreased by attempting to avoid post-machining, by mirroring extrusions, as well as by reducing overall part number and complexity whenever possible. Screw channels in the side rail extrusions, as well as the cartridge extrusions allow for self-tapping screws to fasten directly into these channels. The side rails and cartridge rails are symmetrical, meaning only one extrusion die is required for each. An example of the symmetrical cartridge extrusions can be seen in Figure 11. In total, there are only four different extrusions in the entire design, and two die cast parts. Fasteners are kept to a minimum as well, by utilizing a snap feature to secure the cartridge into the fixture.

Figure 11: Symmetrical Cartridge Extrusions

ASSEMBLY

To decrease recurring costs, the design took into consideration assembly time, to improve on that of the old SOLEIL pendant luminaire. The frame assembly requires a mere 8 screws to connect the side rails to the main housing and the cover is simply slid into the frame, while the cartridges, which also require 8 screws via the cartridge endplates, are assembled separately. Recall that 3 cartridges are then installed in the frame with two screws each. The simplicity of this assembly can be seen in Figure 12. The driver is connected to the frame pre-delivery via two screws that attach to a screw channel. The estimated assembly time for either sub-assembly is of six minutes, as the frame (fourteen fasteners) and the cartridges (twenty-four fasteners) can be built at a rate of fifteen seconds/fastener including the positioning of the components in the assembly jigs. All extrusions also have space within them for wiring, making a normally time-consuming process much simpler.

Figure 12: Frame Assembly

INSTALLATION

To facilitate installation, the frames are first installed in row configuration on site by means of the die cast joiner brackets. This assembly can be seen in Figure 13. These brackets are designed to be fastened together back-to-back by means of a simple screw, as show in Figure 14. Aligner pins are placed in channels within the extrusions to keep everything aligned. The joiner brackets hold everything snug, while the aligner pins keep everything aligned. Aesthetic blanks cover the joiner seams from the bottom, making for a seamless finish. Finally, the cartridges are snapped into place once the row-assembly is hanging from the ceiling. This is to reduce the weight, making it easier for an electrician to install the fixture from a ladder.

Figure 13: Row Configuration Assembly

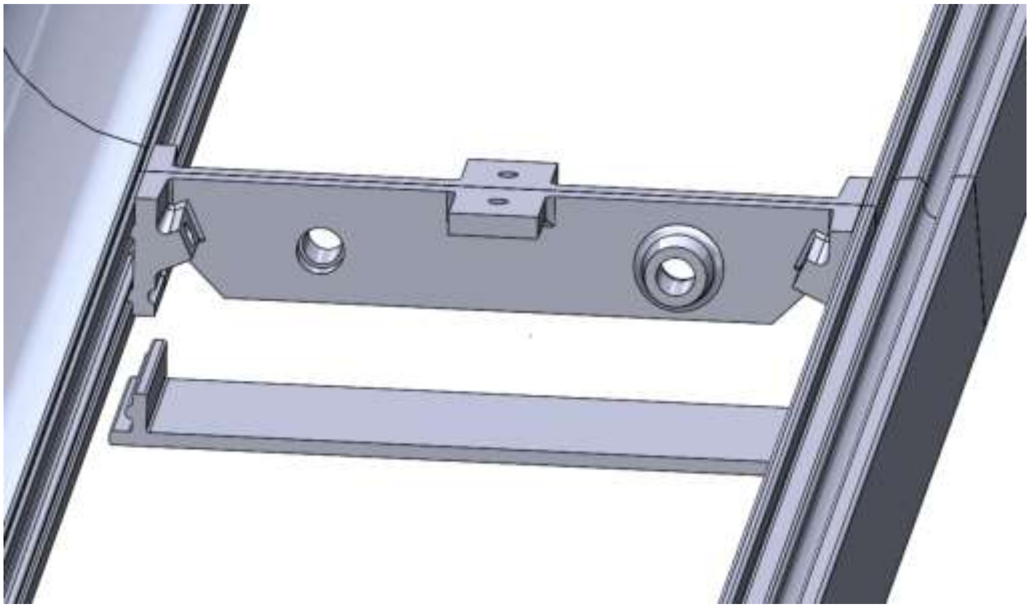


Figure 14: Joiner Brackets Used in Row Configuration

MAINTENANCE

The drivers are easily accessible and replaceable via the access door on the top of the fixture. This door can be pried open with a simple flat-head screwdriver and allows the driver to be changed without having to remove the pendant from the ceiling. The cartridges can also be easily removed by simply snapping them out of the frame. Both of these maintenance features can be seen in Figure 14, with the snap detail shown in Figure 15. Spare cartridges can be supplied by Axis Lighting to its clients, so that should a LED board fail, maintenance personnel can simply replace the cartridge for a new one, and ship the old cartridge to Axis. However, users also have the option of replacing the malfunctioning LED board on site.

Figure 15: Cartridge Installation (Left) and Driver Access Door (Right)

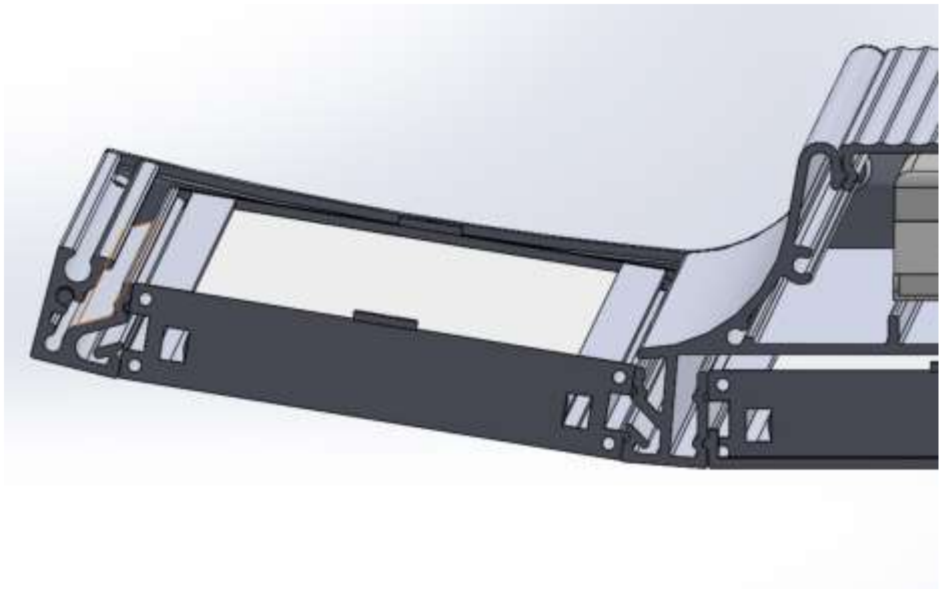


Figure 16: Cartridge Snap Feature

COST ANALYSIS

As previously discussed in the cost analysis phase, the cost was distributed according to the different functions performed. The same analysis was done for the new SOLEIL fixture to compare the cost distribution and ensure value was added. As seen in Figure 17, the function “Support Optics” is the most costly function of the fixture at 73%, representing almost three-quarters of the cost; this is due to the shift towards a more expensive lighting technology. A detailed Bill of Material can be found in Appendix A-9, showing to which function each component belongs.

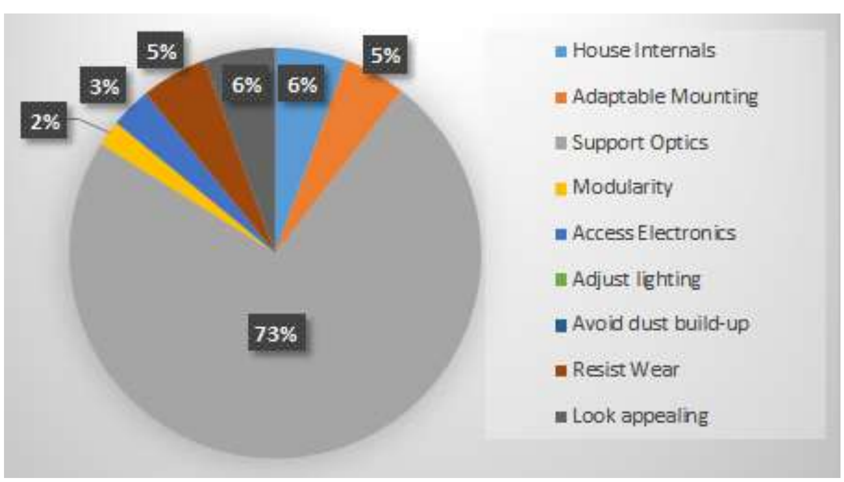


Figure 17: Function Cost Chart of Recommended Proposal

Although it was previously shown that the proposed design provides more value for the end customer, it is important to be able to quantify in dollars how much this product is going to cost over the life of the product. A life cycle cost analysis was therefore used to show the eventual cash flow of the product. All the assumptions used in the calculation of the life cycle cost are listed in Table 6 below. As the retail value is currently unknown, the initial cost of the product assumes a retail sale at cost, without any profit made by Axis Lighting.

As seen in Table 6, the initial cost of the new light fixture represents an expense of $191.38 more than the previous product. Over the lifespan of the fixture, the recurring cost of maintenance of the product generated $82.33 in savings, which are a result of using components with longer lifespans and electricity cost reductions. Taking all the costs into consideration for a time span of 15 years, the new light fixture will cost $109.05 more when compared to the previous version of the SOLEIL design.

Cost Summary	Initial Cost ($CAD)	NPV Life Cycle Cost* ($CAD)	NPV Total Cost* ($CAD)
SOLEIL fluorescent	$ 108.11	$ 357.27	$ 465.38
SOLEIL LED	$ 299.49	$ 274.94	$ 574.43
Savings	$ (191.38)	$ 82.33	$ (109.05)

*Asumptions: Life Cycle analysis over 15 years
Discount rate of 3%
Fluorescent changed every 3 years
Drivers changed every 5 years
Price of electricity 0.0971$/kWh
Lights operating 12h/day

Table 6: NPV of Life cycle cost

CONCLUSION

In conclusion, this value engineering study proposes an upgrade to the existing SOLEIL Pendant Luminaire by incorporating LED technology and increasing value across the life-cycle of the product. Although the upfront cost of the recommended design has increased, the cost of the fixture over a fifteen-year period is only marginally more than its predecessor. Moreover, with the added satisfaction of the needs and interests of easy maintenance, reduced number of parts and assembly time, improved visual appeal, and lower operating costs, the team is confident that the proposed design is significantly more attractive to clients and will assist in the transition towards LED lighting.

Furthermore, the design recommended in this report is aligned with the future direction of Axis Lighting’s portfolio. The proposed fixture implements Axis’s Surround Lite technology for favourable lighting distributions and is flexible for further advancements or pairings of lighting technology; the design also allows for additional electronics to allow for dimming, daylight or motion sensing, and backup power systems. The LEDs are also updatable as technology advances as the cartridge design allows for simple interchanging of LED boards to adjust colour temperatures, different optics and or slimmer light boards.

REFERENCES

[1] M. Wright, "GE Lighting and Lighting Science Group unveil LED circadian lamps", *LEDs Magazine*, 2016.

[2] "SurroundLite Brochure," in *Axis Lighting*, 2014. [Online]. Available: http://www.axislighting.com/cmsAdmin/uploads/SLIM%20SurroundLite%20Brochure_complete.pdf. Accessed: Dec. 2, 2016.

APPENDICES

A-1. INTUITIVE RESEARCH LIST

⌊Good use of appendices.⌋

Verb	Noun	Verb	Noun
Basic Function		**Secondary Function**	
Illuminate	Space	Encapsulate	LED strip
Produce	Light	Encapsulate	Controller
Secondary Function		Enhance	Mood
Provide	Energy	Resist	Wear
Save	Energy	Conserve	Modern look
Regulate	Mood	Integrate	Architecture
Provide	Flexibility	Provide	Opening
Improve	Design	Allow	Customization
Improve	Ambiance	Reduce	Seams
Guide	People	Uniform	Distribution
Be	Durable	Dimming	Capability
Respect	Design	Reduce	Service
Facilitate	Installation	Increase	Performance
Reduce	Maintenance	Improve	Efficiency
Ensure	Reliability	Facilitate	Vision
Connect	Modules	Reduce	Flicker
Transform	Electricity	**Constraint Function**	
Facilitate	Maintenance	Drive	Sales
Hang	Overhead	Incorporate	LED boards
Dissipate	Light	Incorporate	Driver
Diffuse	Light	Incorporate	Light guide
Attract	Buyers		

A-2. REFERENCE PRODUCT ANALYSIS TABLE

Reference Product: Axis SOLEIL Pendant Luminaire	
Part	**Function**
Extrusion base	Hold LED board Hold LED driver Attach to optic panels Hang fixture Protect electronic internals Provide stiffness Create form Mount LED board Mount LED driver
Extrusion side	Hold L/R optic panels Provide stiffness Create form
End cap	Enclose optical panels Enclose side extrusions Create form Provide stiffness Maintain aesthetic Provide rigidity
Optic panel left/right	Diffuse LED light Generate direct light from above Generate indirect light towards ceiling
Optic panel middle	Diffuse LED light Generate direct light from above
LED board	Generate light Light optical panels
LED driver	Power LED board Convert power from AC to DC Reduce voltage Dim LED Control LED Read sensor information
Hanging wire	Suspend luminaire Provide sufficient tensile strength Adjust mounting point
Top access panel	Allow for maintenance Provide easy access to internals Protect circuitry Prevent dust buildup

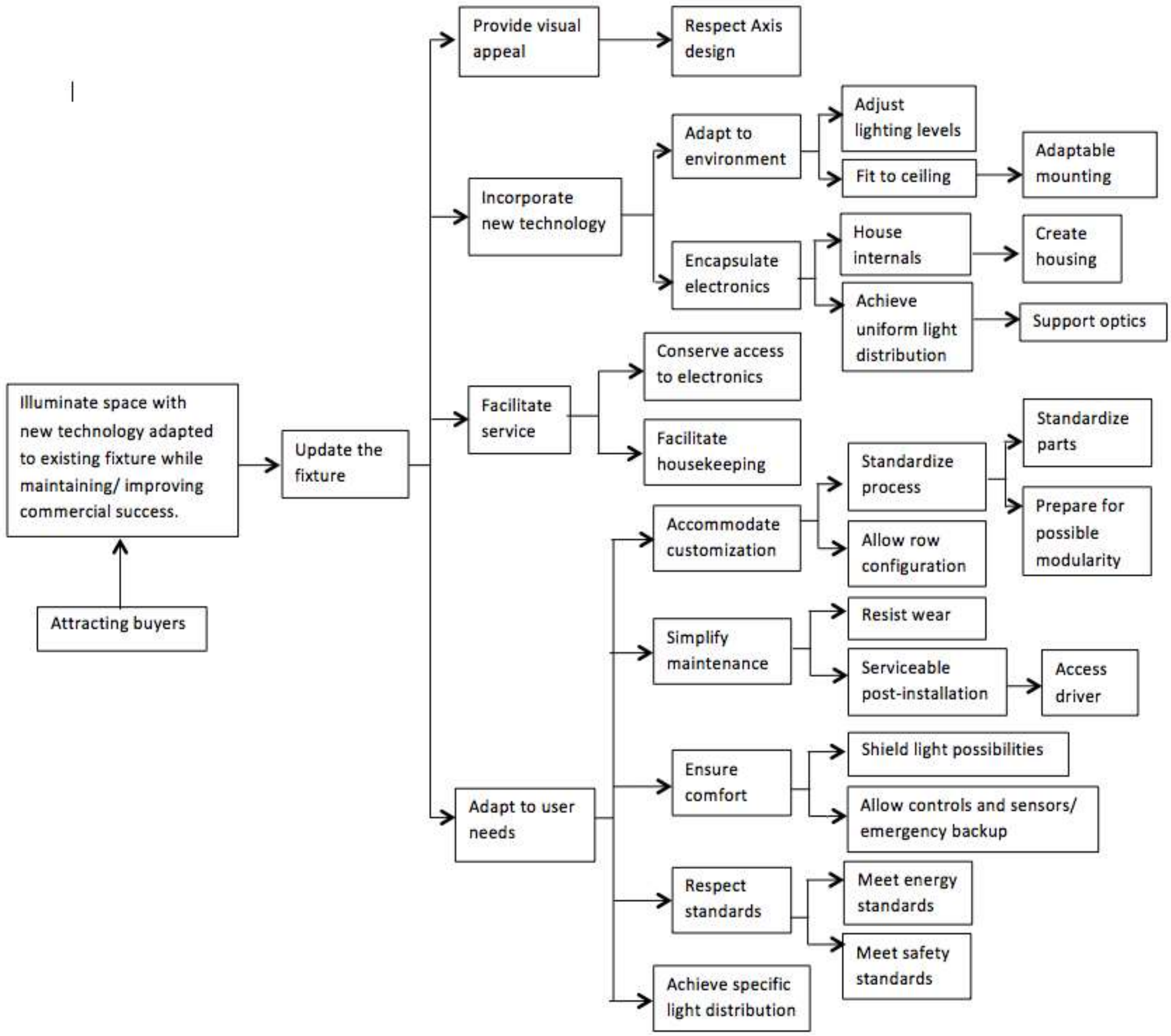
A-3. ENVIRONMENTAL ANALYSIS

Environmental element	**Function**
Space of use	Hang from ceiling Provide aesthetic appeal Comply with Axis design style
Ambient Conditions: -Dust -Daylight -Moisture -Temperature variation	Resist dust Resist moisture Resist UV (paint) Provide stable lighting ability (with change of daylight conditions, dust, bugs, etc) Resist temperature variation
Maintenance -personnel -tools	Allow for easy/quick access to electronic components Allow for repair with real tools Allow for repair while light is still hanging Provide sufficient strength for additional weight on fixture during repair
Installation -personnel -tools -time	Enable quick installation Allow for flexibility in usage (able to install in all ceiling types) Enable installation with standard tools
Users	Provide aesthetic appeal Accommodate users Allow for good light (no flicker, etc)

A-4. SEQUENTIAL ANALYSIS

Sequence	Function
Use Axis shell provided	House internal components Maintain aesthetic appeal
Create extrusions	Support optics House electronics House internal components
Install driver	Power LED boards
Remove/open top of fixture	Access Driver
Create cartridge	Facilitate service Easy access (to optics)
Install lightguide	Diffuse light
Install reflectors & mirrors	Allow for different lighting distribution (direct/indirect/direct & indirect)
Install shielding options	Reduce glare
Install LED's	Increase efficiency Increase customer satisfaction Incorporate new technology
Attach endplates	Secure fixture
Connect fixtures together (daisy chain)	Allow for row configuration Ensure customization capability
Incorporate wire hangers	Facilitate placement (of fixture) Improve versatility Support fixture (to ceiling)
Turn on light	Illuminate space

A-5. FIRST FUNCTIONAL DIAGRAM



A-6. FINAL FUNCTIONAL DIAGRAM

A-7. CHARACTERIZED FUNCTION

Ranking	
1	Vital, Critical
2	Very important
3	Important
4	Desirable
5	Nice to have

Legend	
F0	No flexibility
F1	Little flexible
F2	Some flexibility
F3	Very flexible

Number	Function	Criteria	Level	Flex	Ranking	Notes
1	Look appealing	Clients like the design more than previous model	70% preference rate	+/- 5%	1	The goal is to have a more appealing fixture
1.1	Respect Axis' design	Compare to dimensions and look of shell provided	Maximum width: 18.5 inches Maximum length: 4 ft.	F2	1	the goal of the project is to respect the design provided by Axis
2	Incorporate new technology	Number of LED boards	Between 4 and 6	F0	1	
2.1	Adapt to Architectural Lighting	Modularity		F0	2	
2.1.1	Adjust lighting effect	Number of lighting options	3	F1	2	Provide: direct, indirect or direct & indirect lighting
2.1.2	Fit to ceiling	Number of attaching points	Many	F1	2	Sliding cable
2.1.2.1	Permit Adaptable mounting	Be able to fit ceiling of the client	Can fit 95% of the mounting point	+/- 5%	2	
2.2	Encapsulate	# of visible	1	F1	2	Only the wire

	electronics	electrical components				connecting the driver and the power supply should be visible.
2.2.1	House internals	Number of visible internal components	0	F0	1	Should not be able to see the internal components when looking at fixture
2.2.2	Achieve uniform light distribution	Number of dark spots	0	F0	1	No glare, no dark spots → uniform light
2.2.2.1	Support optics	Number of components	TBD	F0	1	
3	Facilitate service	Reduce maintenance time	XX% faster than previous model	F2	3	
3.1	Be Serviceable post-installation	Reduce maintenance time	XX% faster than previous model	F2	3	
3.1.1	Allow access to electronics	Number of electronics to access	3	F0	1	Should be able to access the driver, LED boards and the wires
3.2	Built from standardized parts	# of standardized parts	TBD	F2	3	
3.3	Facilitate housekeeping	Number of minutes	1	F3	4	
3.3.1	Avoid dust infiltration	Amount of dust inside the enclosure holding the electronics	less than 1000 ppm	F2	3	
4	Adapt to user needs/preferences	Refer to 2.1		F0	1	
4.1	Accommodate customization provisions	- Length of fixture - Type of light distribution	– 4+ ft. – Indirect, Direct, Indirect/Direct	F0	1	
4.1.1	Allow light row	See 4.1				

	configuration					
4.1.2	Achieve specific light	See 2.2.2				
4.2	Require less maintenance	Number of minutes	5 - 10	F1	3	
4.2.1	Resist wear	Number of years without wear	15 years with no wear	F1	2	
4.3	Ensure comfort	Satisfaction of customer	80% satisfaction	F1	2	
4.3.1	Shield light glare	Number of shielding options	TBD	F0	1	
4.3.1.1	Use light shield attachments	See 4.3.1				
4.3.2	Allow manual and automatic controls	- Ability to dim - Sensors present	TBD	F1	3	
4.4	Respect standards	Number of standards met	TBD	F0	1	IEC standards, etc.
4.4.1	Meet energy standards	Number of standards met	TBD	F0	1	
4.4.2	Meet safety standards	Number of standards met	TBD	F0	1	

A-8. GUT FEELING INDEX

Legend	
1	no way, nonsense
2	I don't like it
3	many risks but some hope
4	maybe, let's try
6	not great idea, but some potential
7	Interesting, possible benefits foreseen
8	no risk, very much doable
9	many benefits
10	yessss, let's do it!, champion idea

FUNCTION	IDEA	Gut Feeling Index
Respect axis Design	Scale to avoid interference with bend	10
	Mirrors along side rails	9
	Fasteners on top (better than side/bottom)	8
	Creating steps outside the housing	7
	Width: 11-18 inches,	7
	Length: app 4 inches	8
	4 rows of LEDS	10
	6 rows of LEDS	3
Adaptable Mounting	Slots for the cables along side rail	10
	Sheet metal for support	2

	Deeper channel to the hold the cable		3
	Provide possible support at every four foot section		7
	Hollow extensions		2
	Light guide bending?		2
House Internals & Access to Electronics & Support Optics	Cartridge	U shape	2
		3 (bottom)	7
		3 (Mid-bottom; Side-Top)	10
		1 (bottom)	6
		Hatch to remove driver and remove whole cartridge to change LED boards	1
		Upside down U (See image below)	3
		H-design w/ nut plates	4
	How to access	Fix electronics (no cartridge)	3
		Sliding middle panel to access from top	7
		Magnet	1
		Snapping (similar to remote)	8
		Push in, slide out (like a mouse)	8
		Removable central guide - access form grill or remove the central light guide	6
	Half Cartridge (just moving the driver)	LED’s fixed in place	2
		Driver in small cartridge	4

<table>
<tr><td rowspan="5"></td><td colspan="2">Access from top</td><td>8</td></tr>
<tr><td colspan="2">Frame (Tray) to hold light guide</td><td>4</td></tr>
<tr><td colspan="2">No Cartridge</td><td>6</td></tr>
<tr><td colspan="2">Remove driver from side by removing end cap</td><td>1</td></tr>
<tr><td colspan="2">Holes in light guides: reflecting bushing or acrylic dowel</td><td>1</td></tr>
<tr><td rowspan="6">Fasteners</td><td colspan="2">Magnets</td><td>0</td></tr>
<tr><td colspan="2">Vibration Melting</td><td>1</td></tr>
<tr><td colspan="2">Welding</td><td>1</td></tr>
<tr><td colspan="2">Snap Clips</td><td>10</td></tr>
<tr><td colspan="2">Press fit</td><td>6</td></tr>
<tr><td colspan="2">Screws/Bolts</td><td>8</td></tr>
<tr><td rowspan="8">End caps</td><td colspan="2">Fastened from inside</td><td>9</td></tr>
<tr><td rowspan="2">Flush</td><td>L bracket</td><td>4</td></tr>
<tr><td>End plate</td><td>6</td></tr>
<tr><td rowspan="3">Overlap</td><td>Complete (Over extrusion)</td><td>4</td></tr>
<tr><td>Semi (Over plate only): - L bracket</td><td>6</td></tr>
<tr><td>Semi (Over plate only): - End Bracket</td><td>8</td></tr>
<tr><td colspan="2">Snap/light press fit + screws</td><td>7</td></tr>
<tr><td colspan="2">Spring loaded pins to snap</td><td>2</td></tr>
</table>

	female-female with middle male male piece	3
	Push button locking (umbrella/crutches)	2
	Cap with hollows to fit extending extrusions	3
	Press fit (Junction: circular, separate, extruded, rectangular, etc)	2
	Cable	1
Allow light row configuration	Cable tension	2
	Lego block connection	7
	Rail as two purposes → anti twist measure (b/c would have to extend the extra piece the whole way, which would be expensive)	6
Resist Wear	Adding a coating	1
	Material selection	8
Light shield attachment	Light guide support and clips à Leave a little dip	8
Avoid Dust build up	Easily Swept out	8
	Sealant (as in windows)	6
	Flush Design	10
Safety/Energy standards	Contain a fire	10
	Ventilation	9
	Grated to allow for cooling	8

A-9 BILL OF MATERIALS OF SOLEIL FIXTURE WITH LED TECHNOLOGY

Axis SOLEIL Surround Light Fixture (4ft) Bill of material													
Description	QTY	COST/UNIT	House Internals	Adaptable Mounting	Support Optics	Modularity	Access Electronics	Adjust lighting	Avoid dust build-up	Resist Wear	Look appealing	Cost of Components
Driver	2	$ 13.72			$ 27.44							$ 27.44
Lightguide	3	$ 21.81			$ 65.43							$ 65.43
LED board	8	$ 13.54			$ 108.32							$ 108.32
Optical Overlay Sheet	3	$ 4.00			$ 12.00							$ 12.00
Fixture Core Frame	1	$ 42.46	$ 12.74	$ 4.25			$ 4.25			$ 8.49	$ 12.74	$ 42.46
Housing Cover	1	$ 1.68					$ 1.68					$ 1.68
Side Rails	2	$ 7.01		$ 8.41	$ 2.80					$ 2.80		$ 14.02
Blank	6	$ 0.11									$ 0.66	$ 0.66
Cartridge	3	$ 6.20	$ 3.72		$ 3.72	$ 3.72	$ 3.72			$ 3.72		$ 18.60
cartirdge plate	6	$ 0.18	$ 0.32		$ 0.22					$ 0.54		$ 1.08
End plate Fixture												$ -
End Cap	2	$ 2.90				$ 2.32					$ 3.48	$ 5.80
Sliding cable	2	$ 1.00		$ 2.00								$ 2.00
Screws	8	$ 0.05								$ 0.37		$ 0.37
		Function Cost	$ 16.78	$ 14.66	$ 219.93	$ 6.04	$ 9.65	$ -	$ -	$ 15.92	$ 16.88	$ 299.86
		% cost	5.60%	4.89%	73.34%	2.01%	3.22%	0.00%	0.00%	5.31%	5.63%	

A-10. BILL OF MATERIAL OLD SOLEIL FIXTURE

BILL OF MATERIALS FOR 4FT ASSEMBLY WITH T5 LAMPS													
SOL-VL-30/70-4FT-T5-WH													
PART #	Description	QTY	COST/UNIT	House Internals	Adaptable Mounting	Support Optics	Modularity	Access Electronics	Adjust lighting	Avoid dust build-up	Resist Wear	Look appealing	Cost of Components
SOD-FR-SE-8-WH	Side rails of the frame	1	$ 6.88			$ 6.19					$ 0.69		$ 6.88
SOD-FR-EX-8-WH	Under Center rails of the frame	1	$ 6.88	$ 1.38		$ 4.81					$ 0.69		$ 6.88
SOD-FR-TEX-8-WH	Upper center rails of the frame	1	$ 6.88	$ 1.38		$ 4.81					$ 0.69		$ 6.88
SOD-EX-8-WH	Fixture Core Frame	0.5	$ 8.38	$ 1.26	$ 0.42			$ 1.68			$ 0.42	$ 0.42	$ 4.19
SOD-EC-WH	End Cap	2	$ 9.50				$ 5.70				$ 1.90	$ 11.40	$ 19.00
SOD-FR-EC-3L-WH	End Plate	2	$ 1.58				$ 1.58				$ 1.58		$ 3.16
SOD-SB-WH	End Plate	2	$ 0.90				$ 0.90				$ 0.90		$ 1.80
SOL-FR-LN01	Shield light	1	$ 1.65						$ 1.65				$ 1.65
SOD-SL-BTM-T5	Shield light	2	$ 0.60						$ 1.20				$ 1.20
SOD-SL-TOP-T5-CL	Shield light	2	$ 0.60						$ 1.20				$ 1.20
SOD-REF-WH	Reflector	2	$ 2.18			$ 4.36							$ 4.36
SOD-BUL-CAT	Cable Lock	2	$ 1.00		$ 2.00								$ 2.00
SOD-BUL-CAT-2	Cable Lock	2	$ 0.18		$ 0.36								$ 0.36
CORE-GR-HA-WH	Anchor	2	$ 1.07		$ 2.14								$ 2.14
GRIPLOCK-AXS-18IPE-1420I	Cable Lock	2	$ 1.26		$ 2.52								$ 2.52
SOD-FR-LOCK-UN	Cable Lock	2	$ 0.04		$ 0.08								$ 0.08
SOL-FR-LN02	light panel	1	$ 0.17			$ 0.17							$ 0.17
BALLAST	regulate the current to the lamp	1	$ 43.65			$ 43.65							$ 43.65
			Function Cost	$ 4.01	$ 7.52	$ 64.00	$ 8.18	$ 1.68	$ 4.05	$ -	$ 6.86	$ 11.82	$ 108.11
			% cost	3.71%	6.95%	59.20%	7.57%	1.55%	3.75%	0.00%	6.35%	10.93%	

[Where are the actual tubes & sockets?]