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New heliodon design with the use of Value Engineering (VE)

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Abstract*— We present the new design and development of an automated simulator of the sun´s trajectory (Heliodon). This machine allows the reproduction of the sun´s position and path at a chosen time and place in order to evaluate how sunlight falls on scale models of architectural spaces, with the goal of estimating the levels of sunlight in these spaces. For the development of the plan and level of innovations, we have used value engineering (VE), its work plan, and the effective application of this plan to come up with a new design of an automated solar-path simulator. Emphasis was placed on improving both design and manufacturing in such a way that the cost was reduced without affecting product performance and quality. We found the best possible solution by means of a series of decision tables and technical testing. With the use of this methodology, the benefits of any new product are maximized without lessening its reliability and user´s confidence.

Index Terms—**Architecture, heliodon, sciography, sun´s trajectory, value engineering (VE).**

I. INTRODUCTION

Need for correctly planning and measuring energy consumption and also finding new solutions, new materials and low cost buildings, has increased concerns for experimentation and research in the construction field. Previous to the construction phase in a building project, an alternative to improving energy efficiency of edifications is the execution of solar studies with the use of devices known as heliodons. Making of physical models as artifacts to help in the simulation of sun´s apparent trajectory in the celestial sphere has been carried out since the 30´s in the 20th century, and they have been named in different ways such as solar machine, machine of sun´s trajectory and heliodon [1].

On the other hand, concurrent teams use Value Engineering (VE) methodology to ensure that only the needed functions are present in the design of a product or service and that the product carries out such functions at minimal cost. In this work a value engineering analysis is presented for the performance of two functional heliodons and subsequently, a new heliodon was designed by taking into account the best functions exhibited by the devices analyzed, eliminating those functions that did not add value and coming up with new functions through the automation of the device.

II. BACKGROUND

A. Heliodons

Heliodons are machines or devices whose intention is to mimic sun´s path as it travels through the celestial sphere. Therefore, when light beams coming from heliodon´s lamp hit the building model attached to the heliodon´s platform, a study of the shadows cast on the model can be performed by moving the platform (the model) in relation to the lamp representing the sun. This allows quantifying the amount of light that the real building would receive during the day and let architects to find the best possible orientation to optimize exposure to sunlight. To achieve this, the solar device is constructed so that the model can be oriented at a given location on Earth for a specific time and date [2]. Heliodons are usually constituted by a light source and a platform that supports a mock-up of the edification to be examined. There are several designs of heliodons documented in literature, constituted by a movable light with a fixed platform or a fixed light with a movable platform [3].

B. Value Engineering (VE)

A review of Value Engineering is shown in this section, which is a methodology aimed at designing a product or service at low cost. Central to this methodology is the identification of product´s functions, this must be performed to ensure that all the desired functions that clients demand, are implemented in the product or service. Fig. 1 shows

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a scheme of the basic methodology, used by multidisciplinary teams in the phase of the product design and development process, consisting in the identification of opportunities for improvement and moreover, in the design of new solutions [4].

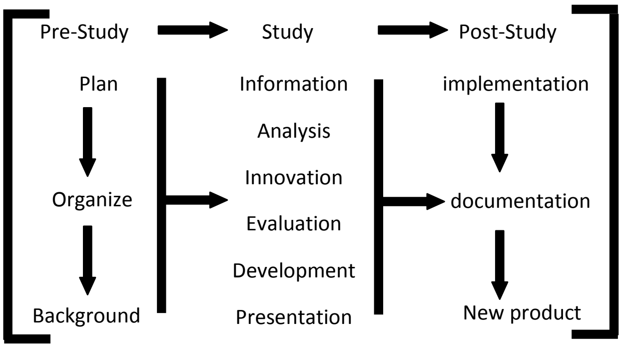

Fig 1. Stages of Value Engineering (VE), after [7].

The concept of value is defined in Eq. (1), which relates satisfaction of internal and external clients´ needs to resources that are utilized to satisfy them [5], [6]. Value is then a measure of how good or bad a product, a process or a service satisfies client´s needs in relation to the resources consumed to make the product (or the process or the service) [7].

$$\text{Value} = \text{satisfaction of needs/resources used} \qquad (1).$$

Application of this methodology consists of three stages: pre-study, study and post-study. In the first stage, value study activities are planned and organized, scope and objectives are determined, and value team is set. In the second stage, purpose is to carry out the six phases of the value plan to: understand the project, identify its functions, develop design alternatives, narrow down options and present the winner. Finally, new design proposal is implemented and project report is prepared. The scope of the present work is centered in the study stage shown through a case study.

III. CASE STUDY

A. Collection of Information [7]

To identify the needs of heliodons´ users and the functions required for these devices, two universities with a specialty in bioclimatic architecture were visited in Mexico, where there are different configurations of heliodons. In Fig. 2(a), a heliodon designed and owned by Universidad Autónoma Metropolitana-Azcapotzalco (UAMA) is shown, where this machine is of the type having a fixed light source and a movable platform. In Fig. 2(b) a machine belonging to Escuela Superior de Ingeniería y Arquitectura-Tecamachalco of Instituto Politécnico Nacional (ESIA-IPN) has a semi-fixed platform and a mobile light source.

B. Function Analysis [7]

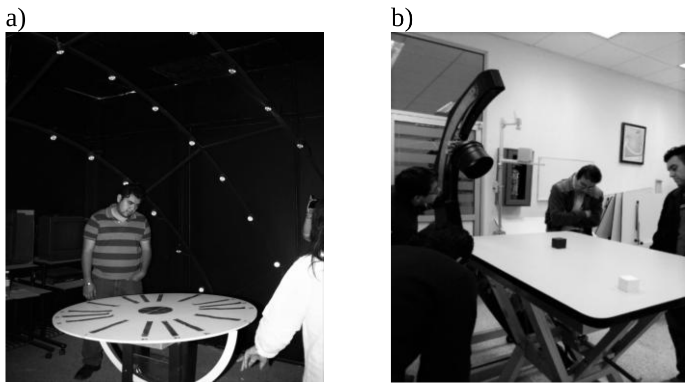

Fig 2. Heliodon´s pictures taken on site: (a) device with movable platform, (b) device with movable light.

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Identification of functions is one of the most important and difficult steps of this methodology since it is where the designer has to know user´s needs very well and from that, functions that meet such needs are defined and further described [5]. Usually, functions are identified by nature, by importance and by effect in this sequence. Field research allowed identification of main and secondary functions. Analysis and classification of primary and secondary functions of the machine´s parts under study were carried out.

For the purpose of the present study, three main subsystems of the heliodon were identified: date positioning, location positioning and illumination. As an example, Table I shows the function identification matrix for the lamp assembly, an important part of the illumination subsystem. It was realized after analysis, that a low energy consumption system might be implemented instead of the lighting system in current heliodons, and also emission of parallel rays might be improved to avoid dispersion of light that caused unnecessary shadows in the studied system.

Table I. Function identification matrix for the lamp subsystem.

Relevant Component	Function	Principal	Secondary
Lamp	Emit parallel rays	X	
	Generate shadows	X	
	Save energy	X	
Cable	Carry electricity lamp		X
Switch	Interrupt or conduct electric current to lamp	X	

IV. FUNCTION WEIGHING

Once that heliodon´s parts were analyzed and their functions determined for each main subsystem, a weighed comparison was carried out to evaluate the interrelationship existing among all the components and the functions they perform. High value relationships indicate a vital component-function relation, whereas a low value points out an irrelevant relation. Table II displays weighing used in the evaluation [8]. Again as an example, evaluation of the illumination subsystem is presented. The components of this subsystem had a direct and high relationship with the function "emit light of good quality", but the components of the positioning subsystem had a weak relationship with this same function. This kind of comparison was executed for each subsystem and each function for the whole system. This stage ends by summing up the points for each component and those parts with high number of points were considered for improvement and those components with low score were able to be modified slightly or eliminated. Table III shows these results, where platform (58 points=17%) and its support (45 points=13.19%) were modified with great detail without decreasing their functionality, whereas for components such as wheels (24 points=7%), indicator (22 points=6.45%), and gage plate (24 points=7%), their modifications were small due to their low scores.

Table II. Weighing coefficients and meaning.

Importance of the function-component relation	Coefficient
Useful	1
Necessary	2
Important	3
Very important	4
Vital	5

Table III. Value analysis results. Comparison and allocation of points for some components.

Factor	Component	Points	Percentage
A	Table	58	17
B	Support for table	45	13.19
C	Wheels	24	7.03
D	Plate 1	29	8.50
E	Shaft	22	6.45
F	Plate 2	24	7.03
G	Handle	36	10.55
H	Ball bearing	38	11.14
I	Bar	39	11.43

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J	Switch	26	7.62
	Total	341	100

Interviews with users of heliodons also showed a new problem partially solved in current designs. The need for high accuracy was evident in existing heliodons, and to respond to this need it was thought in improving control of machine´s main movements. To achieve this, design team and users agreed in that automation of the machine would improve accuracy in the study of shadows. Criteria for elaboration of proposals to obtain such innovation were:

a) Appraisal. Determine gaps between current and ideal states.

b) Alternatives. Propose them based on new materials, new processes, new criteria.

c) Implementations. Carry out changes without losing functionality.

A. *SAFE Diagram*

Another tool used to represent machine´s functions is the Sequential Analysis of Functional Elements (SAFE) diagram [8]. It consists in functional and sequential diagram of every component contained in the three main heliodon´s subsystems: location positioning, date and time positioning and lighting. Fig. 3 shows a simplified diagram displaying the functions identified for each of these subsystems, followed by corresponding components that perform each of those functions.

SAFE sequence in Fig. 3 helped to identify areas having the most opportunity for improvement. The function "adjust something" can be done manually or with automatic control. In most current heliodons adjustment of parameters is manual, so it was decided to carry out machine´s control through automation, specifically those components that needed to be adjusted, with the benefit of obtaining very accurate shadow measurements. Other relevant opportunity of improvement was sought in light quality. Common heliodons´ lamp does not cast light perpendicularly enough upon worksurface, therefore a new lens design was proposed along with change in the type of lamp used to eliminate this problem. Next section deepens details of these improvements.

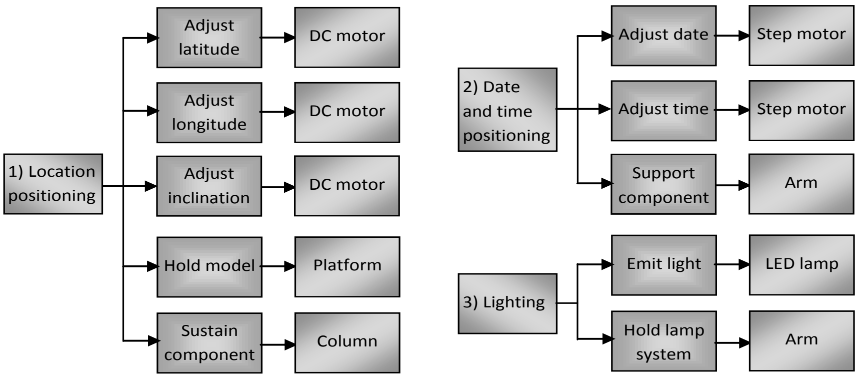

Fig 3. SAFE diagram of main subsystems: Subsystem → Functions→ Components, after [8].

B. Innovation [7]

In this stage, tools such as morphologic analysis function and evaluation matrices were used to promote creativity in order to refine conceptual design changes and implement a functional prototype [9]. Creativity was required to maximize those functions with high weight and to eliminate unnecessary functions. Manufacturing requirements were also thought about and Design for Manufacturing and Assembly (DMA) guidelines were used to reduce unnecessary manufacturing and assembly operations, consequently reducing fabrication costs [10]. Final design proposal that met design and manufacturing requirements consisted of the following subsystems and characteristics:

a) Location positioning, consisted of a worktable and a support made of lightweight materials such as alucobond and duralumin, both components were designed in a commercial CAD system and fabricated in CNC milling machines. In the assembly, direct current (DC) motors were mounted in the support and they were used to give the proper terrestrial coordinates and inclination to the work surface, Fig. 4a.

b) Date and time positioning, consisted of an arm of alucobond designed in a CAD system and fabricated with CNC machines, which holds and moves the lighting subsystem and the step motors that move it to the time of the day and

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date of the year desired to perform the study. Movement from step motors to illumination subsystem is transmitted through toothed belts and pulleys, Fig. 4b.

c) Lighting subsystem, composed of a LED lamp and a parabolic lens which when mounted together, allowed the illumination of the model in a more realistic way than in current heliodons, and similar to real sunlight. Mounting parts and heat dissipater were also included, Fig. 4c.

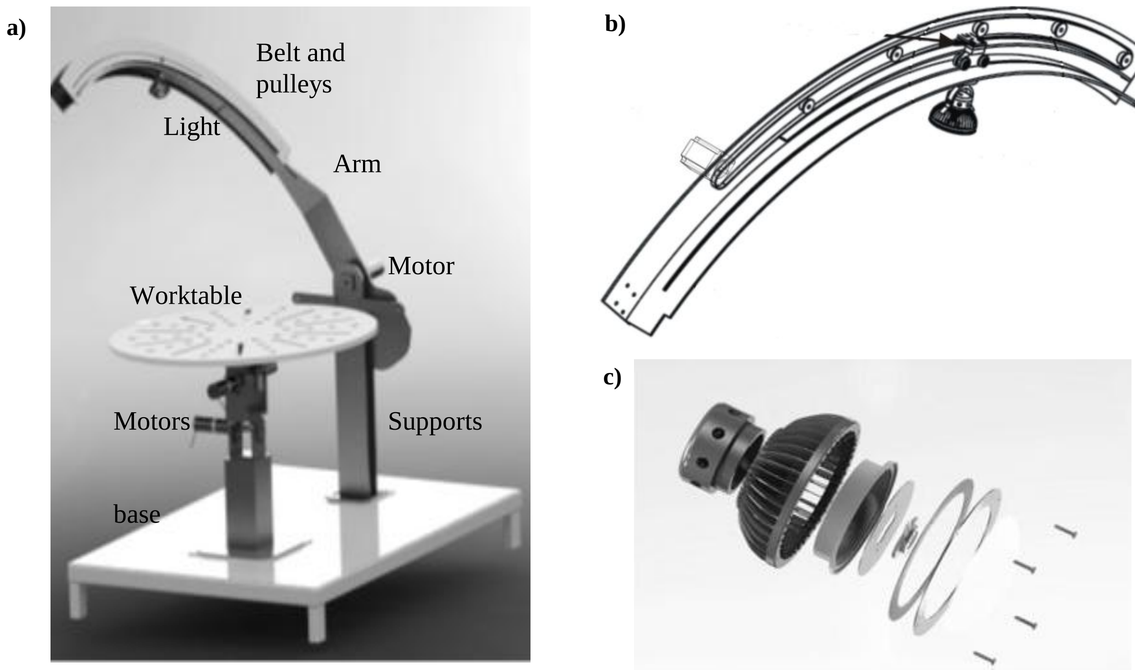

Fig 4. CAD sketches of heliodon´s new design: a) main parts, b) belt and pulleys, c) lighting subsystem.

C. Development, evaluation and presentation [7]

Activities of the design process depicted in Fig. 5 were adapted also in this stage of VE. To develop a functional machine, design for manufacturing and assembly instructions were followed to optimize these activities, according to Boothroyd and Dewhurst [10]. Specifically, guidelines for selection of Materials and Processes, for Manual Assembly and for Machining were applied. Components were classified according to machining process, material, shape, size, insertion, handling and manipulation compatibility, to ease manufacturing and assembly of final product, reducing time and improving final quality. One hundred and sixty-eight pieces of duralumin, alucobond and steel were machined in CNC lathe, CNC milling machine and water jet cutting. CAM strategies were planned and simulated in commercial software and CNC G-codes were also generated.

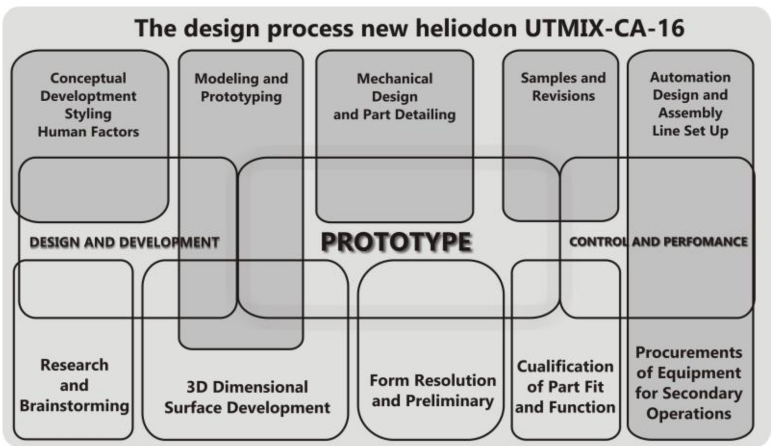

Fig 5. The design process for new heliodon.

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Light emission is fundamental in this machine in order to generate high quality shadows. Traditional heliodons use incandescent lamps for this purpose, therefore illumination subsystem was an area of opportunity for strong improvement, since incandescent lamps have a wide beam and are less power efficient than other types of lamps. With the recent boom in LED lighting technology, LED lamp options are nearly infinite. For this reason, different types of carefully selected lamps were tested to arrive at a better lighting solution. A spotlight LED lamp type was chosen because it allowed casting light in a focused area, with the desired light intensity, narrow light beam, low energy consumption and extended lifespan. Incandescent, halogen and fluorescent lamps do not have these characteristics because they commonly spread light in a wide light beam. Fig. 6 shows comparison of wattage consumption for given light output. For example, LED lamps in average consume 5 watts (W) for an output of 450 lumens (Lm), however fluorescent requires 12 W and incandescent 40 W to give the same light output. Similar trend is observed for any other light output value [11]. Fig. 7 displays efficacy and lifespan for different lamp types. Both efficacy and lifespan are way superior in LED lamps than in other lamp types [12], [13]. Incandescent lamps have an average efficacy of 11 lumens/watts (Lm/W) and an expected lifespan of 3000 hours (h). On the contrary, LED lamps have 125 lumen/watts and last 40000 hours of service in average, and halogen and fluorescent are in between these performances.

Finally, whole evaluation of the system included verification of worktable´s movements control and revision of quality of shadows by expert users, Fig. 8. Final presentation consisted of documentation that supports the creation of a heliodon´s new design through the application of value engineering methodology and its development, implementation and conclusion to produce a high value, low cost solution.

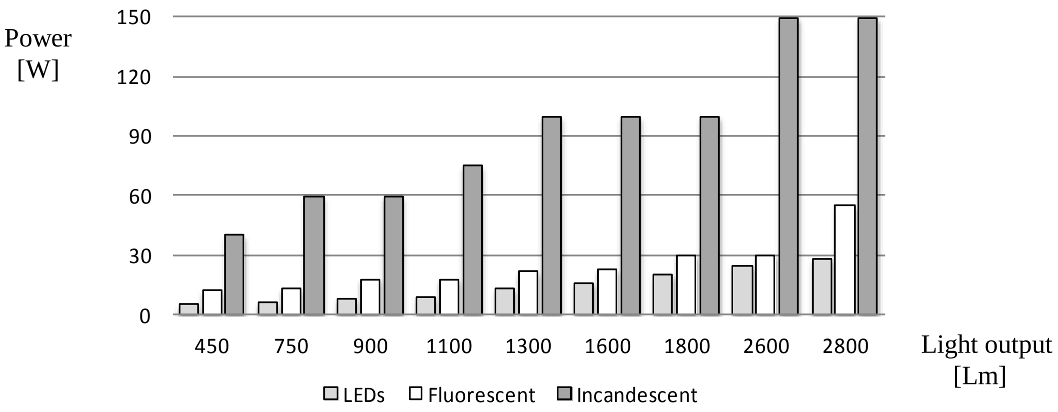

Fig 6. Comparison of power consumption versus light output for several lamp types [11].

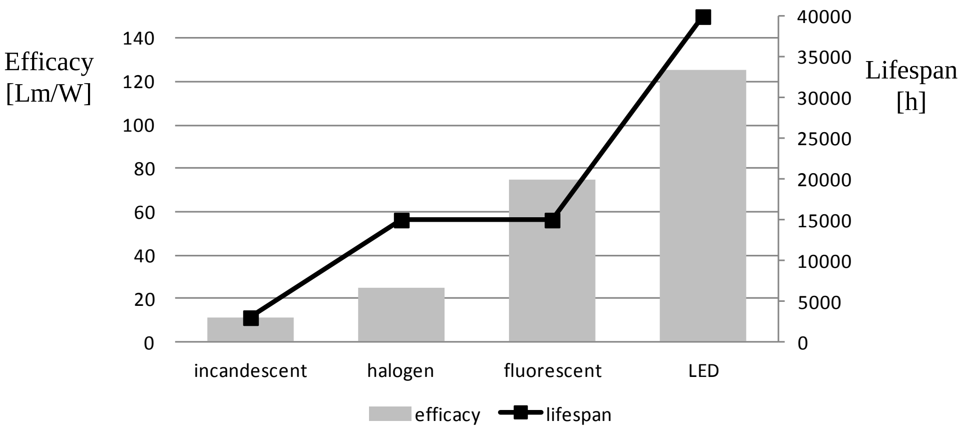

Fig 7. Efficacy and lifespan for several lamp types [12], [13].

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Fig 8. New heliodon´s performance evaluation on site for an architectural model.

V. CONCLUSION

Value engineering is a methodology that uses a systematic analysis to find and select the best value alternatives of designs, materials, processes and services. VE was successfully implemented in coming up with an entirely new heliodon´s design capable of simulating sun´s trajectory and that surpasses previous designs´ performance while keeping the essential functions needed by users of this machine. Tools used and activities carried out in this work were screening and determination of components´ functions, function weighing, SAFE method, design proposals, design for manufacturing and assembly, prototype construction and general test of the machine. It was possible to implement improvements in design, manufacturing, functionality and performance with respect to existent systems. Relevant changes consisted of a spotlight LED lamp, use of lightweight materials and automatization of the heliodon´s movement to increase accuracy in shading studies. Regarding machine´s manufacturing, design for manufacturing procedures and CAD/CAM technology were used to reduce cost and accelerate design planning, fabrication, assembly and testing.

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