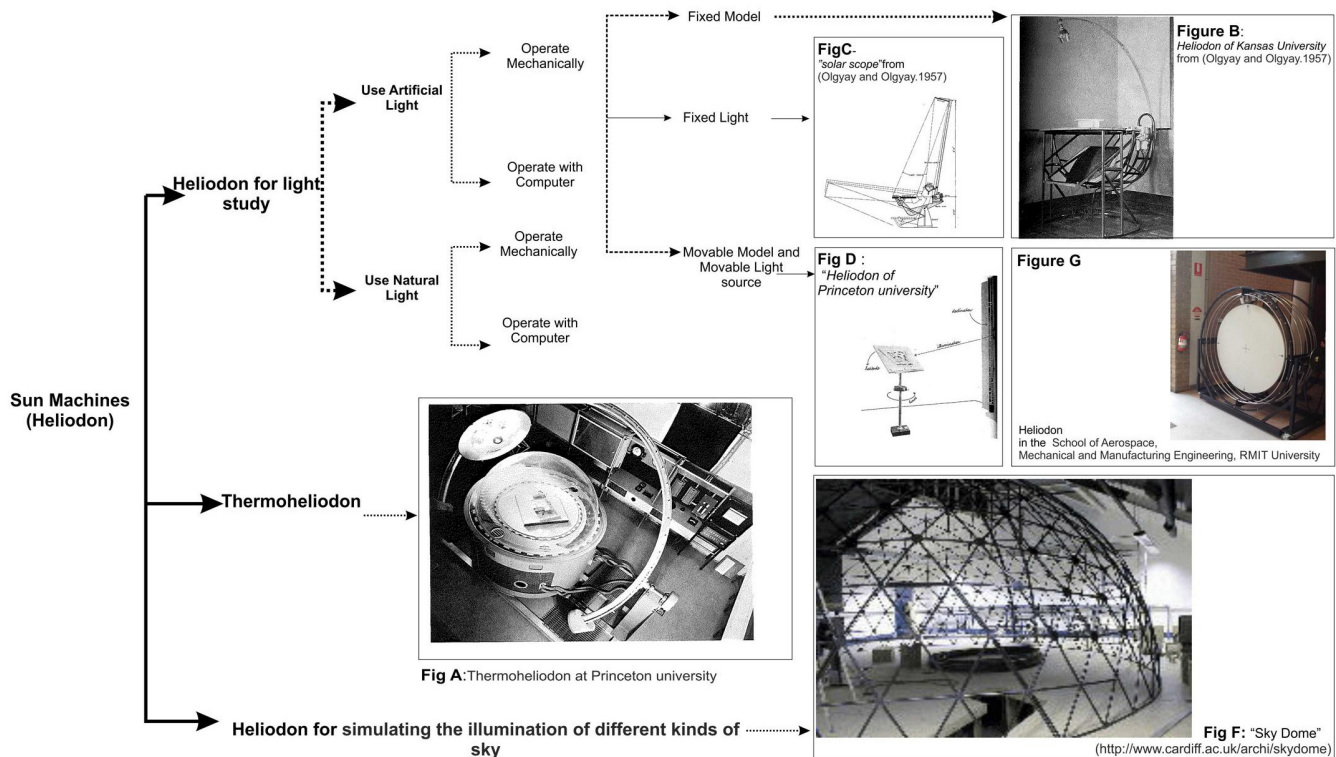


# ROBOTHERMODON

AN ARTIFICIAL SUN STUDY LAB  
WITH A ROBOT ARM AND ADVANCED  
MODEL PLATFORM

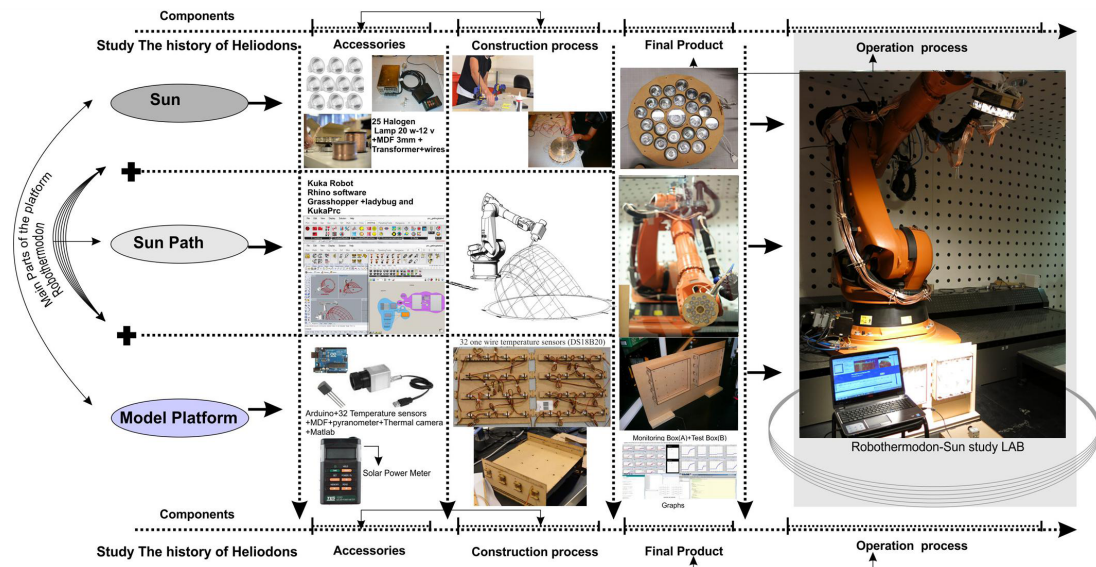
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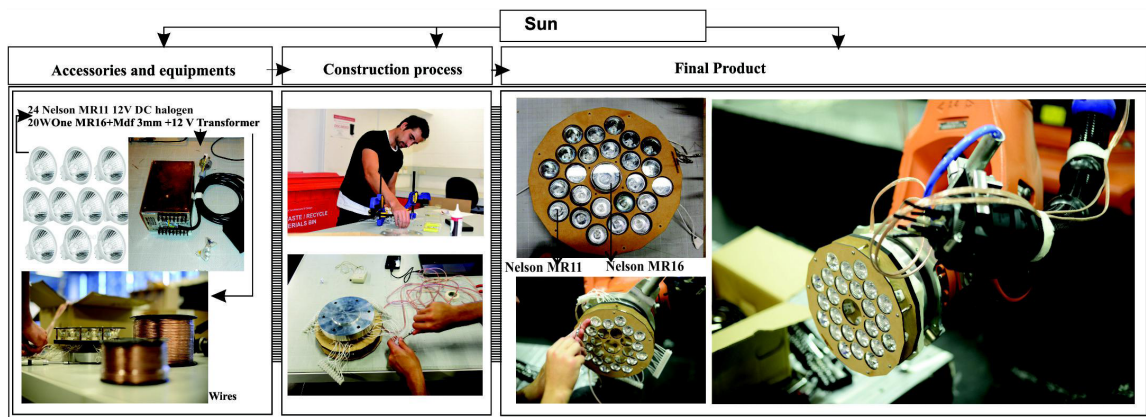
## ABSTRACT

This research focuses on the design of a Robotic solar analysis platform for critical studies which explore dynamic solar light and heat phenomena within the laboratory. This robotic platform gives designers the opportunity to receive rapid feedback from physical models in real time. The aim of this paper is to propose a solar evaluation platform within the physical domain to engage investigators with tangible experimentation techniques, which may lead to an increased ability to understand the computational process. The aim of this thermal heliodon is to create a method of solar analysis with the aid of the robot and using its inherent capabilities and CNC flexibilities to engage students and researchers with this mixed physical or digital simulation platform. A novel design of a robot-controlled heliodon to simulate the motion of the Sun is described. It is a simple and relatively low cost accessory, fitted to the robot arm and can easily change the construction laboratory into a sun study lab. This platform gives researchers and students who have access to the robot, the ability to integrate the physical nature of light and heat within the early stage of their design process.

- 1 Classification of Heliodons based on their general functions with sample pictures including – Fig A : Thermoheliodon at Princeton University (Olgyay and Olgyay 1957); Fig B,C and D: "Sun Machine Types" (Olgyay and Olgyay); Fig E: Heliodon of the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University; Fig F: "Sky dome" at Welsh University (<http://www.cardiff.ac.uk/archi/skydome>)



2 Robothermodon main components and Sun Lab Setup Process



3 Construction process and the final product of Sun for the platform

## INTRODUCTION

In ancient Greek mythology, Helios was the personification of the Sun, hence the name, the heliodon. Heliodons are used to observe the interaction of light with a physical model prototype. They are costly to build, but they are good instruments for increasing a user's perception of the environment and environmental parameters which impact on building performance. This particular exploration of the heliodon will reveal the possibilities for physical explorations of solar phenomena with the added advantage of the many degrees of freedom of a robot arm. The Sun's path will be mapped with the robot while controlling the intensity of the light and heat to achieve the necessary thermal intensity over the Sun's path. This method does not directly relate to the actual conditions outside, but does provide a platform to optimize façade performance based on direct solar exposure. In this paper, we describe the first exploration of energy studies with the robot in the architectural field. This paper will go through the history of the heliodon to get a general view of the similar platforms and give a short

summary of different heliodon configurations. Then it will cover the construction process of the Robothermodon platform and present analysis techniques as well as assessment procedures. Finally, the possibilities for the thermal heliodon platform will be discussed as a precursor for future experimentation.

## HELIODONS: BACKGROUND

A heliodon or "*Sun machine*" is a teaching and research device to study the Sun's effects on building designs for various latitudes, dates and time of the day by placing physical models on the platform.<sup>1</sup>

Monitoring physical prototypes at reduced scales and comparing the results with full-scale buildings is one of the methods of analysis with the heliodon. Different kinds of heliodon have been developed over the years as sun study tools for solar analysis and evaluation of physical models. The standard heliodon platform gives users the potential of observing the Sun's location around the

building while, in some cases, giving them the opportunity of heat and sky illumination analysis. Hence, the heliodes developed so far could be broadly classified into three main generations based on their general functions (Figure 1). Most of them fall under the sun study category, used for studying the Sun's position and sun-light effects on buildings or examining shading devices for eliminating direct sun from the exposed areas. In this category, two main kinds of light sources are used: natural light which requires an outdoor apparatus with the real sun and sky and artificial light for indoor laboratory.<sup>2</sup> Some of them consist of a movable sun and a fixed table while some others have a movable table and a fixed light source (Figure 1).

The thermoheliodon of Princeton University was built for studying the thermal behavior of physical models beyond just studying the shadows created by the sun position.<sup>3</sup> Another kind of heliodon, named the "sky dome", was developed at the Welsh University to simulate the illumination of different kinds of sky.<sup>4</sup>

In general, a heliodon is a good device for investigators as it gives them tangible feedback about the effects of the Sun's movement relative to their building and assists designers and researchers in getting rapid feedback on their physical models.

## ROBOHELIODON AND SUN LAB SETUP PROCESS

After studying configurations of various Heliodes, we concluded that three main components are fundamental for this Robotic Sun study lab including:

1. Sun;
2. Sun path; and
3. Model platform (Figure 2).

The key advantages of using the Robothermodon and its incorporation of the latest technology will be described in the related three categories mentioned.

### SUN

At this stage of the project it is important to be able to provide adequate light and heat intensities with control over these two critical variables. The current design incorporates the ability to dim the lights through digital pulses generated from an Arduino wirelessly controlled via a computer. With further investigation during the experimentation and evaluation phases of this project, we expect to compute and upload the intensities of the Sun that correspond with the Sun's position in the sky. The light and heat source for

the artificial sun consists of twenty-four Nelson MR11 12V DC halogen lamps rated at 20W each. The lamps are embedded on a MDF base, which is bolted to the solid aluminum attachment plate for the *Kuka* robot face (Figure 3).

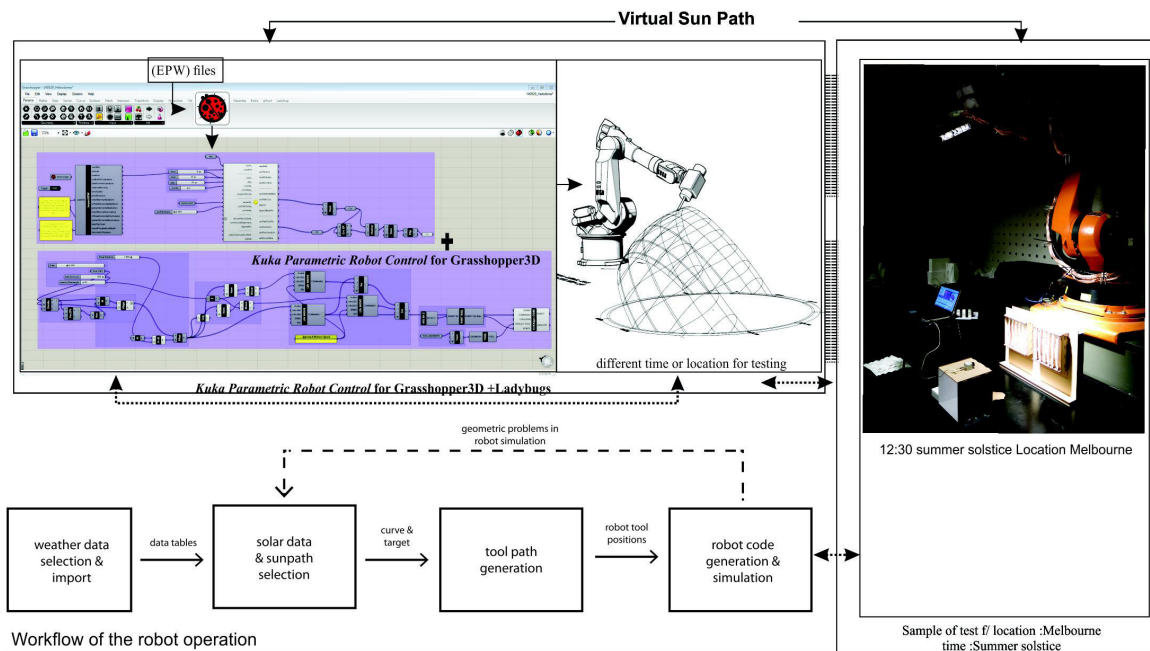
The actual in-situ performance of the lamps will be detailed in a subsequent paper, which will evaluate the key technical characteristics of the robotic thermal heliodon. The current limitations of this particular artificial Sun do not allow us to simulate the effects of the diffused ambient radiation. Within the subsequent experiments to be performed in the first four phases of experimentation and validation, the diffusivity of light is not a major factor when evaluating facades for thermal performance (see model platform section). The thermal gradient projected from the halogen lamps has been documented and will be used to error correct variations in temperature across the test domain sensor grid. The effects due to ambient diffuse radiation within the lab will be covered in more rigorous experiments to follow in later phases of this ongoing research project.

### SUN PATH

The most significant contribution of this platform is the selection of a virtual sun path; the generation and simulation of a *Kuka* robotic arm which moves along this trajectory. Unlike a conventional heliodon with a track for the Sun as a joint ring mounted on the simulation platform, this setup uses the capacity to program a generic robot arm, a device which is becoming increasingly accessible in design schools (Figure 4).

In this project, the digital sun path was extracted from a data file using *Ladybug*,<sup>5</sup> an open source environmental plugin for *Grasshopper3D* in *McNeel Rhinoceros 5.0*. This plugin is one of several recently developed tools addressing weather data and simulation. It includes the capacity to convert selected data from standard EnergyPlus Weather (EPW) files into a geometric curve in the Rhinoceros modeling environment. This geometry was then used to generate a sequence of tool locations for a robotic arm and then converted to code which drives the robot. In this case, this was achieved using the *Kuka Parametric Robot Control* for *Grasshopper3D*.<sup>6</sup>

The common *Grasshopper3D* platform of these plugins allowed for the entire workflow to be managed in a single parametric model. This provided significant flexibility in selecting conditions for study, allowing the robot program file to be automatically updated as a different time or location for testing was selected. Some feedback from the robot simulation to sun path selection was required as the physical geometric limits of a given robot and enclosure provided constraints. Unlike some design exercises



4 Virtual Sun Path with Ladybug and Kuka Parametric Robot Control

utilizing such robotic prototyping for a given simulation location, the solution space of possible paths was clearly bounded, meaning that all sun path permutations could be confidently resolved through the identification of extreme cases and the identification of constraining limits within these.

## MODEL PLATFORM

The other key novel contribution of this Sun Study Lab is the distinctive design of the model platform, distinguishing it from the previous traditional heliodons. The proposed exploratory platform for placing the designed models is not just a simple table. It is advanced with various sensors and equipment that enable users to classify various results in terms of assumed criteria and the extracted data from a series of experiments. These processes go through two main stages: a) data collection, and b) data visualization and analysis, including a series of physical experiments and digital visualizations (Figure 5).

## DATA COLLECTION

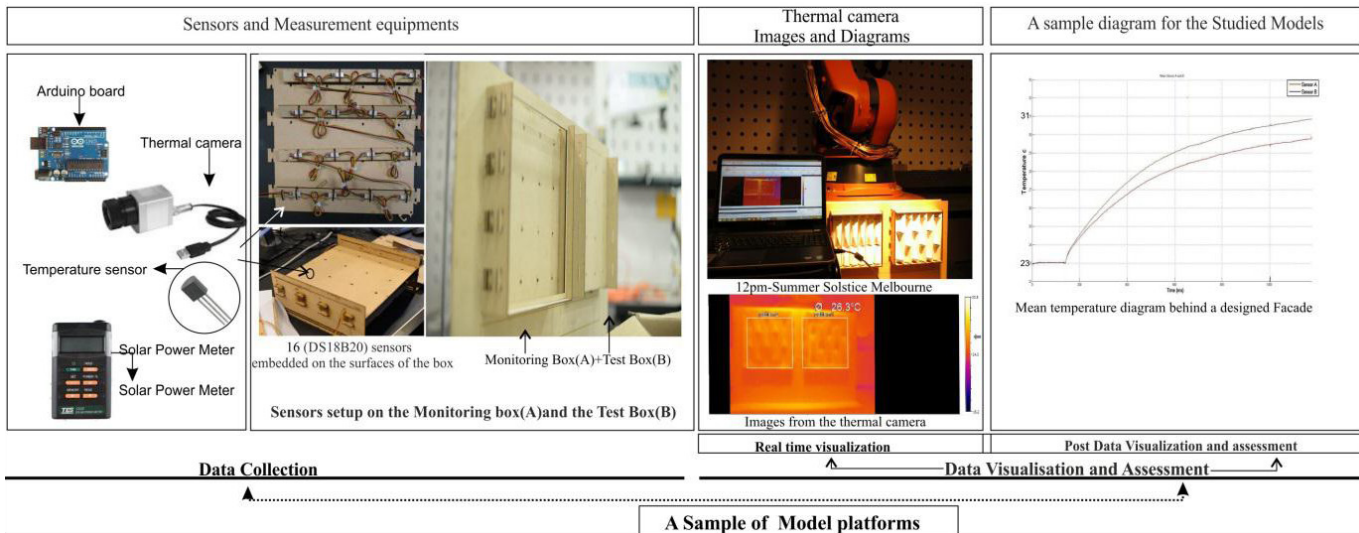
The data collection stage involves gathering surface temperature data with a thermal camera and readings from thirty-two temperature sensors (ds18b20), similar tools to those used in *"Thermal Reticulation cluster of Smart Geometry 2013"*.<sup>7</sup> A pyrometer was used during measurements of the thermal gradient projected from the halogen lamps. The first case study of the model platform involves the design of a dual testing domain apparatus. One to be used as a control during experimentation and the other as the test

domain for placing the under investigation. They are attached to the ninety times sixty centimeters MDF panels representing the wall of an existing building (to which the designed façade geometry should be applied externally). The 'control box', named "Box A", is designed to monitor the effects of changing temperatures through a standard which provides a relative measure for the thermal performance of the designed surfaces to be attached to the test domain. The designed façade geometry should be attached externally to the second box which is named "Box B" or the test domain.

There are thirty-two digital one wire temperature sensors (ds18b20) which are embedded in the three millimeter MDF in a four by four grid within the control and test domains (sixteen sensors in each domain). The sensors are configured to measure the amount of heat that is transmitted through the façade design (Figure 5). The thermal camera, which provides thermal images of the different design surfaces, is positioned in front of the domains to measure the surface temperature of the façade design.

## DATA VISUALIZATION AND ASSESSMENT

The extracted data from the thermal camera and the sensor measurements will be analyzed and visualized using MATLAB which enables researchers to gain insight from the extracted data (Figure 5). This stage enables the researcher to get feedback on their designed models visually and gives them the opportunity of comparing the extracted data for detailed assessment processes.



5 Platform Setup Process with a Sample of Visualization.

The first design of the model platform was created for analyzing the thermal performance of folded geometry. A case study was performed where students were asked to test their designed geometries in the platform, the results will be published soon.

## THE EXPERIMENTATION AND VALIDATION PHASES

We defined five phases for this research.

Phase one: the design of the artificial sun and the operation of the robot, which is covered in this paper. Through these phases, it is expected that this system provides at least the accuracy and validity of the traditional heliodon. However, it will provide very precise and instant control of light through CNC capabilities and manipulability of the robot. This platform will accommodate a variety of model scales and a dynamic representation of daylight over a day.

Future Phases are:

Phase two: The evaluation of the radiant intensity gradients of the artificial Sun.

Phase three: Validation of the test domain with various materials with known thermal characteristics.

Phase four: Experimentation with complex façade geometry with reference to a control surface.

Phase five: Explorations into diffusivity and expanding the flexibility of the test domain.

## ADVANTAGES AND FUTURE APPLICATIONS

This platform displays advantages for architecture pedagogy by engaging students and investigators with tangible experimentation techniques, which may lead to an increased ability to understand the computational process of solar analysis. The growing plethora of digital simulation tools for solar analysis creates disparity in the quality of simulated results in virtual space. The complications

within the algorithmic solvers of each software package will differ, as will the results. The infinite user-defined variables and domains involved in computational solar analysis create another level of diversity and stratification of simulated results. These levels of complexity create difficulties in the classroom in practice. Students of architecture, in general, are not interested in the technological specifics of a virtual simulation tool. So, results are likely to be non-existent, unverifiable or inaccurate due to oversights in the analytical process. Learning different software takes time and the users' different levels of knowledge have strong effects on the outcomes. This platform is very user friendly and investigators can get rapid feedback on their designed surfaces just by attaching their sample models to the existing platform, even for conceptual models.

The size of this platform is adjustable which permits the possibility of various degrees of scale model to be tested in future applications. Observation of the solar phenomena produced within the platform and the analyses of light access, the heat island effect and shadows on surfaces even for urban scale models. Of course there are restrictions in scale imposed by the size of the laboratory and the capabilities of the robot.

The Robothermodon is also capable of studying multiple parameters for multi-criteria optimization. The designed study platform of this Robothermodon brings the opportunity of adding different kinds of sensors like wind and light sensors, for exploring other natural phenomena that may have an influence on the thermal performance of facades under simulated radiation.

## CONCLUSION

This paper presents an overview of the progressive research and creation of heliodons in the past. Through this exploration into the specifics of each platform, the Robothermodon has been placed into this research domain as a valuable novel creation with the added benefits through the flexibility of a *Kuka* robot arm. The combination of the virtually controlled sun path with the ability to sense digitally the temperature gradients within the test domains provides the opportunity for the tangible virtual interface to stream real time data for on-the-fly discussions regarding solar thermal performance of façade systems. This is ideal for the engagement of students and their instructors and professionals in the architectural field. Furthermore, the value of two testing domains can be exploited for quick and accurate feedback to meet multi-criteria optimization goals. It is an exciting prospect to harness the power and the patterns of the Sun within the laboratory and will lead to breakthroughs in the design of systems for improvements in solar performance.

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## NOTES

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## IMAGE CREDITS

Figure 1: Olgyay, A. and Olgyay V. (1957) *Solar Control and Shading Devices*. Cardiff University. "Sky dome." <http://www.cardiff.ac.uk/archi/skydome>

Figure 2-5: Image credits to Authors (2014).

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