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6th INTERNATIONAL ACADEMIC CONFERENCE ON PLACES AND TECHNOLOGIES

PLACES AND TECHNOLOGIES 2019

THE 6th INTERNATIONAL ACADEMIC CONFERENCE ON PLACES AND TECHNOLOGIES

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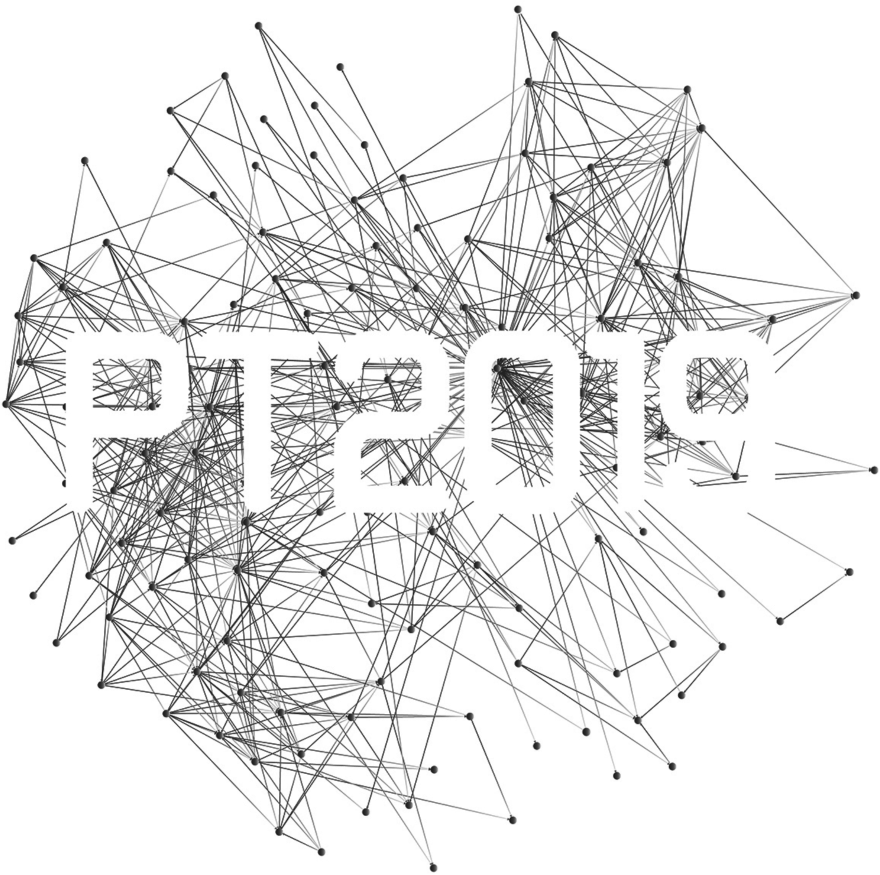

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TABLE OF CONTENTS

PLENARY LECTURE 44

PAPER 89

MECHATRONICS IN ARCHITECTURE: DESIGN RESEARCH METHODOLOGY

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ABSTRACT

Complex modeling presents new and contemporary subject in architecture. The loop between the idea, programming, digital modeling and physical models gives the possibility to come to new conclusions that help develop architectural projects. This paper aims to show the advantages of multidisciplinary architectural projects through a workshop held at the University of Belgrade - Faculty of Architecture. The participants of this workshop, from different backgrounds and faculties, have been doing a research about the use of mechatronics in architecture. The mechatronic system was analyzed on a physical model based on the project by the architectural studio 4of7 Architecture for Slavija square in Belgrade. One of the aims of this workshop was to show the user-object-environment relationship and to explore the advantages and disadvantages of this kind of architectural design. The final product of this workshop is an interactive physical model that can show the movement of architectural elements in real-time. This model can help in the education about the use of mechatronics as a new design method in architecture. The concluding argument would show the possibilities of mechatronics in architectural projects for urban space and it will aim to place it on the map of design methodologies in architecture.

Keywords: mechatronics, design research, architectural design, model

INTRODUCTION

New technologies in computer modeling influence the design process and change architectural concepts in the 21st century. The relationship between the user, an object and its environment becomes much more complex, since new knowledge opens new possibilities. Design research methodology is used to investigate these relationships to be able to make conclusions for further research of this subject. The aim of the workshop based on mechatronics, held at University of Belgrade, Faculty of Architecture, was to explore one of these relationships and to show the advantages and disadvantages of its use in architectural design. The challenge was to develop a methodology for interdisciplinary workshops through the work on a responsive scale model. The final product of this workshop is an interactive model, changeable in real time, which shows the

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use of mechatronics for movement of architectural elements. Hypothesis is that this example will show the possibilities which mechatronics introduce in architectural design. Besides, this workshop contributes to the education of students and points to new methods they could use later in practice.
The use of mechatronics in architecture demands collaboration among architects, mechanical engineers and programmers. Interdisciplinary workshops contribute to better understanding of different fields and the creation of high quality projects which show new possibilities in architecture and other fields. (Meyboom, Wojtowicz, Johnson, 2010) This paper will show that experts from different fields can work together on creating a new reactive environment in urban design by using mechatronics.
The outcome of the workshop and the influence of mechatronics on architecture, as well as the ambient it creates in urban space, will be shown in the conclusion. At the same time the review of the possibilities of this developing idea in design will be examined and placed as the basis for further research of this field.

RESEARCH DEVELOPMENT

The starting point of research for the workshop was the winning project for Slavija square in Belgrade, Serbia of the architectural studio 4of7 Architecture in the year 2013. Presented project is a system of 88 lamps which form a new ambient in urban space based on its disposition and movement. These lamps are movable and work on mechatronic principles. Simple mechatronic system consists of three elements: input, controller and output. This system can become more complex depending of the project needs. In architecture, mechatronics can be used for the movement of architectural elements in real time. Input is generated by different types of sensors which register information from its surroundings, conduct them to the actuator, usually a motor or a screen. (Stojanovic, Milos, Vujovic, 2015) In this project, sensors register changes in the surroundings and then conduct information to the motor which moves the lamps. The whole system is managed with a software that controls lamp rotation and its speed based on the information from the sensors. One of the aims of the workshop is to test this system, its idea and functionality, as well as to test new possible elements that would contribute to the ambient value of the project and develop stronger relationship with the users of the square.
The decision to test the application of this system has come from the desire to conduct an interdisciplinary workshop with the aim to connect students from different fields in development of mechatronics in architecture. A model was an appropriate media for testing all the principles set in this project, and to be, at the same time, the means for student education.
System of 88 lamps detects the number of users, meteorological conditions, level of pollen in the air, level of gases, etc. The information is then sent to the motor which initiates the rotation of a lamp. (Stojanovic, 2015) This system couldn’t be applied in the model, because sensors don’t have enough information in the interior to influence the movement of lamps. Also, the size of the model and its profitability wouldn’t be achieved if there were as many motors as lamps. Therefore, the decision was to test other types of movement. Translation in horizontal directions was implemented and the rotation of the lamps was kept, while the number of sensors was minimized to only one type that measures the users distance. Based on that, the concept of movement in the model was that closeness of users influences the movement of lamps. While there are no users, the lamps would rotate, and when a user got close to the model, the lamps would translate towards him. To fulfill the demands of the model concept, it was necessary to organize an interdisciplinary workshop for architects, mechanical and electrical engineers to make such a complex model.

WORKSHOP STRUCTURE

The workshop lasted for one semester and it included experts from different fields and students from different levels of study, in order to develop a responsive scale model. The mentor of the workshop was Djordje Stojanović, the lead architects and designer for Slavija square, which was used as the inspiration for the model. Another mentor was the professor Marko Miloš from the Faculty of Mechanical Engineering who helped his students develop the mechanical components of the model. An electrical engineer, Nikola Krajnović, used to supervise the workshop and help with the model assembly, especially of the electrical segments and their programming. Milica Vujović, PhD student for Spain, participated in the design of the model, its scale and relation between different elements, together with the PhD students of architecture from Belgrade. The total number of participants was 8. The collaboration among PhD students from the Faculty of Architecture and master students from the Faculty of Mechanical Engineering was successful. The key for a successful workshop was the combination of students from various fields of research: Architectural design, Architectural engineering, Design in mechanical engineering and Mechanical engineering and information technologies; as well as in good work organization and the commitment of all participants. Tasks were given based on the expertise and preferences of students, but everyone worked as a team in assembling the model. The constant interaction among participants was necessary since changes happen during the work on the model. Working together on solving the developed problems led to advancement in design, but it didn't change the primary concept of the model.

MAKING OF THE MODEL

Working frame for the model was made based on the design proposal for Slavija square. The first question was asked: How can 88 lamps move if there is no motor for each lamp? If we assume that base of the lamp is fixed and its top movable on an imaginary path, and that all lamps are parallel to each other, it can be concluded that the ends of a lamp are in two planes, one fixed and one movable. When position of planes rotates, placing the fixed plane above the movable one on a calculated distance, all lamps will be able to move by moving only one plane. The upper plane was scaled to complement the visual effect of the model. Each lamp had its own path, so their rotation and translation contributed the concept for the model. (Figure 1) Distance of the planes, as well as the incline of the lamps, was easily calculated through the relation of dimensions and angles of the lamps. This calculation also helped determine the diameter of holes for the lamps in the upper plane, hence giving them its position in the model. (Figure 2)

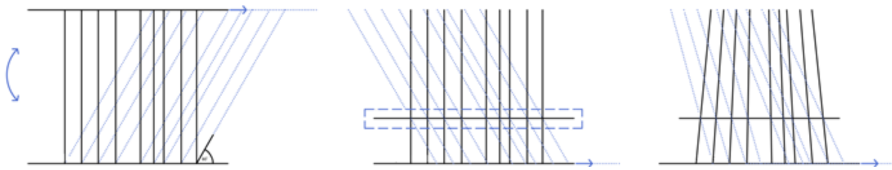
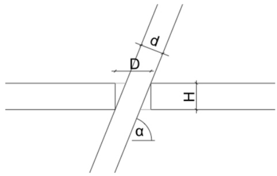


Figure 1: Position of planes



$$D = \frac{d + H\cos\alpha}{\sin\alpha}$$

Figure 2: Calculation for the diameter of holes

The following question was related to the mechanism that would move the lamps. Where is the mechanism positioned and how will it move the plane that initiates the movement of lamps? The participants came to the conclusion that there would be one motor for rotation, another for translation in the direction of one axis, and the third one for translation in the direction of the other orthogonal axis. However, it opened up the possibility of moving the plane diagonally which additionally contributed to the dynamics of the movement of lamps. Design of the mechanism, with all of its accompanying parts, was given to the student that did his masters in Design in mechanical engineering. Elements of the mechanism were: one carrying board for gear racks, two gears for translation, while one part of the board was the gear rack for the rotation gear attached to the motor. Beside that, it was necessary to design the girders for these elements. With the mechanism of the model, four sensors have been placed to detect the proximity of the users and to send the information to the motors.

The last elements of the model give the solution for the illumination of lamps. In order for all the lamps to have the same illumination, a board with LED (Light-Emitting-Diode) lights was placed in the model, under the diffuser (acrylic board). This element of the model was placed bellow the part that held the lamps, in order for the lamps to fall onto the diffuser. Lamps were made out of transparent acrylic board which conducts the light the same as optical fibers, so they shine with their whole length.

All the elements of the model were connected with screw bolts which enables quick and easy change of the elements. This type of connections leaves the possibility for further interventions on the model, thus placing it into the category of models with high changeability. (Abadi Abbo, 1996) Also, this enables the use of the model in educational purposes and for further research.

The program that moves the model controls all of its elements. The code has been written by the student that did his masters in Mechanical engineering and information technologies with the help of the electrical engineer. The code defined the movement of the motors, their speed, rotation of the gears and the relation of sensors based on the closeness of users. Besides the movement, the code also controlled the level of illumination of lamps.

Basic elements of the program hardware are three servo motors, type MG995, that have a stall torque of 12 kg/cm, four ultrasonic sensors which measure the distance of the users from the model and a microcontroller Arduno UNO used for the communication among sensors and actuators. Other hardware components are LED tapes, Darlington driver, proto board, jumper wires and a power supply with the voltage of 5 V or 12 V.

Program software was written in IDE developed by the company Arduino for the use of their microcontrollers, based on a program language C. Servo motors consist of DC motor and a control unit for precise control of the motor rotation. Movement of the motor was initiated by the sensors and was limited by the code to 180^{o}. The sensors measure the distance by sending an ultrasonic pulse that deflects on the user and returns to the sensor. The path is defined with a simple calculation written into the program. Considering that the user can move quickly, in order not to compromise the movement of the lamps, a filter was written in the code that enables smooth movement. LE diodes are controlled with a PWM signal. The code is written on

a computer and then transferred to Arduino. The model starts moving when the power supply is turned on.
When all of this information is put into the mechatronic system input-controller-output it can be concluded that its use in this project is very simple. Input is the closeness of the user and it effects the sensors which conduct information to the motor. Outputs are the reactions to the movement of the motor, ie rotation and translation of the lamps, as well as the illumination of the lamps. Controller is the program which moves the model. (Figure 3)

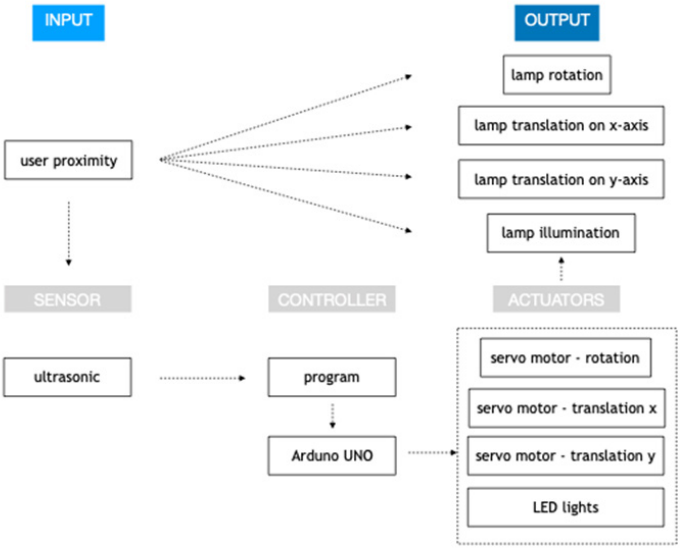


Figure 3: Mechatronics diagram

Problems that emerged during the making of the model were mostly of mechanical nature and they were solved on the go. One of them was the solution of the carrying elements for the mechanism, sensors and the upper board with lamps. To achieve a certain aesthetic quality of the model, the decision was made for the girders to carry all the elements of the model in four points, not to disrupt the movement of the mechanism. These girders were dimensioned based on the idea that all the elements on the model have to be visible in order for everyone to see how the model works. After combining all the elements and turning on the model's power supply a problem occurred, the movement of the gear on the rack plane was difficult, because the gear was weighted. The solution for this problem was to add acrylic boards with a hole for the gear in order to alleviate the movement of the gear rack. When the acrylic boards were placed, the problem was solved.

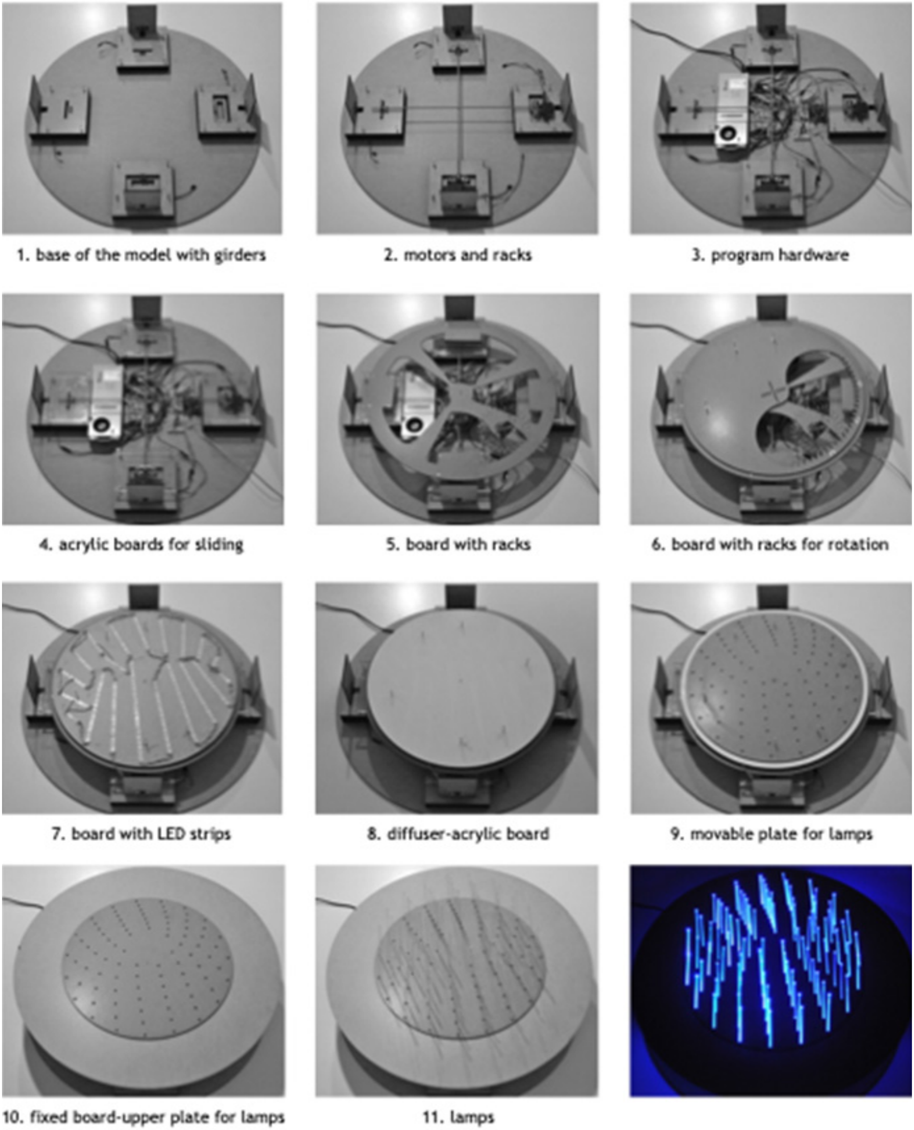


Figure 4: Elements of the model - the way of arranging the boards

WORKSHOP RESULTS

After the completion of the model, all the results have been summarized and further development of this concept was discussed. First of all, it has to be emphasized that the goals of this workshop were fulfilled. The end product of the workshop is a reactive, changeable model that enables testing of a design strategy in real time. New techniques of movement synchronization have been tried out. Interdisciplinary collaboration was achieved, which contributed to better understanding of future experts in different fields of research and their communication that could continue even after the workshop was done. Besides, this workshop has a strong educational character. Through this workshop students have been introduced to the mechatronic principles in architecture, and the model will be used for education students in the following generations.

The contribution of this type of workshops in the field of application of computer modeling in architecture is grand. To start, it contributes to the education of young architects that can later apply mechatronics in their architectural practice. During the workshop, through the interaction with other professions, architecture students were introduced to the principles on which mechatronics work, and also with the process of programming the controller that starts the whole model. This workshop opened the possibility of collaboration among different professions in order to achieve something innovative. It also pointed to the wider use of mechatronics in architecture to influence the relationship between the user, an object and its environment, as mentioned previously in the paper. However, the problem of this type of research is that it usually stays inside the academic community. Modern age researchers try to develop different computer programs to accompany the architectural design process, but they are usually applied in workshops at universities, and are rarely open to the public, so their application in the architectural practice is small. (Popovic Larsen, Tyas, 2003) Even thought the design for Slavija square was publicly presented and won an architectural competition, mechatronic principle did not come across wider application in practice. The concept for the square has grown into a five year research project funded by the Ministry of science and technologies. (Stojanovic, 2015)

DISCUSSION

Since the idea for the model was based on the design for Slavija square and the use of mechatronics for the system of rotating lamps, the concept for the workshop was to test and complement the design for this project. The concept was to make the model based on the principles applied in the design for Slavija square with slight modifications because of the given workshop conditions. Therefore, the number of sensors and motors that participate in the movement of lamps was decreased, but their movement was more dynamic and the illumination was given more character. The ultrasonic sensor was chosen to detect the approximate of the user and translation was introduced. Moving 88 lamps at once with the mechanism that works on three motors was a very complex solution, so the workshop lasted longer than what was initially planed. During the model assembly it was suggested to have all the elements connected with screw bolts, which made the assembly easier, as well as easier modification of the model. Programming of the controller was reduced to a simple principle of transferring information, from sensors to the motors, from the motors to the lamps, from the led lights to the lamps… This way of programming is flexible because it enables easy change of data just by changing the initial parameters (incline of the lamps, speed of the motor, intensity of light…).

Possible changes in the concept for the workshop are the size of the model and the division of works among participants. The movement of lamps could have been tested on a number of smaller scale models, starting with simpler solutions to more complex ones, which was also affect the division of work, and could show the different ways of implementing mechatronics in architectural projects. Another solution could have been to have four separate systems that would be controlled with the four sensors already placed on the model. In this way, the movement of the lamps would be more realistic, since the ones further away maybe wouldn't have moved at all. This was partially the case in this model. The workshop shown in this paper has given a model that is transformable and assembled as a working model for further research, but for now, it only shows one way of implementation of mechatronics in architecture.

CONCLUSION

Interdisciplinary workshop presents one of the most efficient design research methodologies. It is good for education and the collaboration among different professions. Through these workshops new knowledge is accumulated, and new conclusions can be achieved, and can become the basis for further research.

The use of mechatronics in architecture was tested on the design concept of the studio 4of7 Architecture for Slavija square. Movement of 88 lamps that create the specific ambient of a public square was made possible with the use of sensors, controllers and actuators. Simple application of mechatronics in this project was the basis for starting the workshop.

The conclusions after the completion of the model are based on a comparative analysis between the project and the model. The most noticeable difference is in the movement of the lamps. In the project it is limited only to the speed of rotation, in the model it depends on the proximity of users, so they move translatory towards them, while in the starting position they rotate. Besides, the illumination was modified in the model. It also depends on the proximity of the user. When the user moves closer, they shine brighter. However, the most interesting conclusion is related to the use of the model. It can be changed and modified in real time by changing the elements or by reprogramming the code. The greatest advantage of this workshop is that its result- the model, serves for presentation, education and research of the use of mechatronics in architecture. The quality of the model provides its durability, while transformability enables its further use.

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