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CONCEPT DESIGN AND ENGINEERING ANALYZES OF MODULAR INTERIOR OF DOUBLE-DECKER PASSENGER TRAIN

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A b s t r a c t: In this paper an attempt to find the most appropriate solution concept for designing the interior of a double-decker passenger train from ready-to-use modules is presented. The guiding idea is to apply the most appropriate form of modules that will provide their easy and efficient coupling, multiplication, flexibility in spatial displacement, possibility of recombination, etc. The presented idea is developed in the form of several types of flexible systems of coupling modules for first and second class seats and a module for persons with disabilities. By applying algorithmic design, an algorithm is designed that forms the arrangement of modules in a double-decker coach. The testing phase is finished with the application of modern engineering methods examining the ergonomics of the new concept and the natural and artificial lighting in the coach.

Key words: modular design; futuristic design; algorithm design; nesting design; accessibility; eco design

КОНЦЕПТ ДИЗАЈН И ИНЖЕНЕРСКИ АНАЛИЗИ НА МОДУЛАРЕН ЕНТЕРИЕР НА ДВОКАТЕН ПАТНИЧКИ ВОЗ

А п с т р а к т: Во рамките на овој труд е презентиран обид за изнаоѓање на најсоодветно решение, концепт, за формирање на ентериер од готови модули за изградба на двокатен патнички воз. Водечка идеја беше изнаоѓање на најсоодветна форма на модулите која ќе обезбеди нивно лесно и ефикасно спојување, мултиплицирање, флексибилност во просторното разместување, можност за рекомбинација итн. Презентираната идеја е разработена во вид на неколку типови флексибилни системи за спојување на модули на седиштa за I, II класа и модули за лица со инвалидитет. Со примена на алгоритамскиот дизајн се дизајнира алгоритам кој го формира распоредот на модулите во еден двокатен вагон. Направено е испитување со помош на современи инженерски методи за ергономијата на новиот дизајн и за природното и вештачко осветлување во вагонот.

Клучни зборови: модуларен дизајн; дизајнирање со помош на алгоритам; дизајн со помош на вмрежување; пристапност; еколошки дизајн

INTRODUCTION

Societies around the world are looking for alternatives to their transportation needs. The need for making passenger rail vehicles for public transport is very important for economic, environmental and industrial aspects. Today about 80% of employees are traveling to work individually with their own transport vehicle that is designed for 5 persons so that is unprofitable and the intention is to reduce the rate and increase the percentage of use of public transport. Modern vehicles for passenger transport should be carefully designed to offer a fun, comfortable and convenient travel and thus to encourage more people to use [6, 7, 8].

Lately worldwide rail vehicles become topical because of the economy, speed and comfort. Most modern double-decker trains are fast. The bi-level passenger train has two levels of travel accommodation, which increases the capacity of passengers in some cases up to 57% per car. The use of

double-decker coaches can solve the problem by increasing the capacity of the train, excluding other options for changing the infrastructure by building longer trains, with an increased number of trains per hour or building new tracks next to the existing ones. The purpose of this research is to determine the performance and technical capabilities for a new generation of interior double-decker passenger train through the creation of a new method of modular design. The new modular interior is designed using all modern rules of design, safety, accessibility, lighting, ergonomics and standards used in the use of materials and colors in production [1].

INSPIRATION FOR DEFINING THE SHAPE AND CONNECTION OF THE MODULES

With the help of bionics, i.e. the analysis of the form, color and function of the vertebrae in the giraffe derived the idea of connecting the modules. The giraffe neck is composed of a series of similar shaped bones called vertebrae (Fig. 1).

Fig. 1. Vertebrae in the giraffe

Like other mammals, the giraffe has seven neck vertebrae of similar size. The modules are connected in a linear array that provides a solid structure and necessary balance. Like the vertebrae, the modules in the train are completing their function only when coupled in series, while independently as a separate entity have no function [10].

A CONCEPT OF THE BASIC FORM OF THE THREE-DIMENSIONAL MODULE

Because the interior is of a modular character, the basic shape of the three components (for I, II and class for the disabled) is the same for easy and efficient mounting, dismounting, flexibility in spatial displacing, the possibility of recombination etc. The module has fixed dimensions – width and height, where only the length can vary. The body of the vehicle can be modulated in the longitudinal direction.

The concept is based on the application of three-dimensional rectangular modules that will form the structure of the interior. The Fig. 2 shows 2D layout of connected modules with rectangular base.

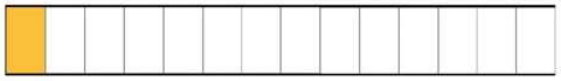

Fig. 2. 2D layout of connected modules with rectangular base

Rectangular prisms represent the simplest geometric form that allows easy and efficient coupling, multiplier flexibility in spatial displacement and the possibility of recombination. It also allows a spacious comfort. Three types of modular capsules were designed: Module for I class, II class and the module for the disabled.

A CONCEPT OF MODULAR INTERIOR DESIGN FOR I CLASS

Module I class is designed to accommodate six passengers (Fig. 3). The major task for the design of the module for I class is to provide greater comfort. It is designed also to form a semi-enclosed capsule enclosed by glass area (electronic glass). The seats in the module are larger than in the other two modules, so they allow the greatest comfort.

Fig. 3. Three-dimensional view of the module I class

Technical drawing for the first class module is shown on Fig. 4.

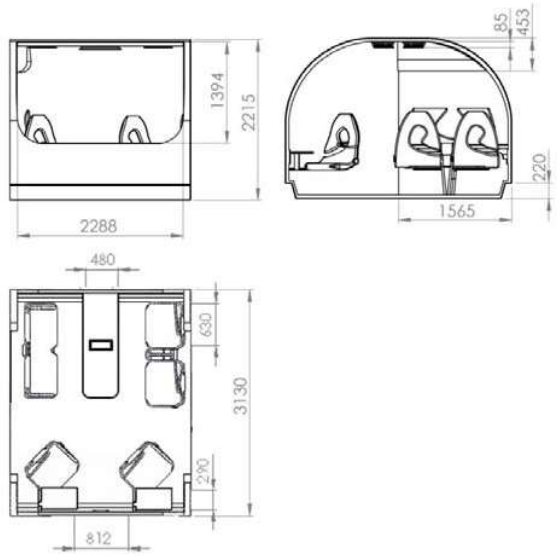

Fig. 4 Dimensions for the module for I class

The 3D appearance of connected multiple modules of I class in the double-decker passenger train is shown on Fig. 5.

Fig. 5. Joined modules of I class in longitudinal direction

A CONCEPT OF THREE-DIMENSIONAL MODULE FOR II CLASS

The module for II class is designed for eight passengers with 2 + 2 seats. Both seats are placed next to each other on the console that aims to keep the seats fixed at a certain height from the floor. The arm rest is designed to be used at the same time by two passengers. That is provided with two different heights for setting the hands to rest. In each seat headphones are fitted and each passenger can choose specifically what to hear. The side windows have tilted rectangular shape which gives a sense of dynamism and speed.

The difference between the three types of the module for II class is that different seating is combined with table or storage. The first type is generally a 2 × 2 seats facing back to back. Storage area is located in the upper right corner and below the ceiling (Fig. 6).

Fig. 6. 3D view of the module for class II type 1

Technical drawings for the module for II class are shows on the Fig. 7.

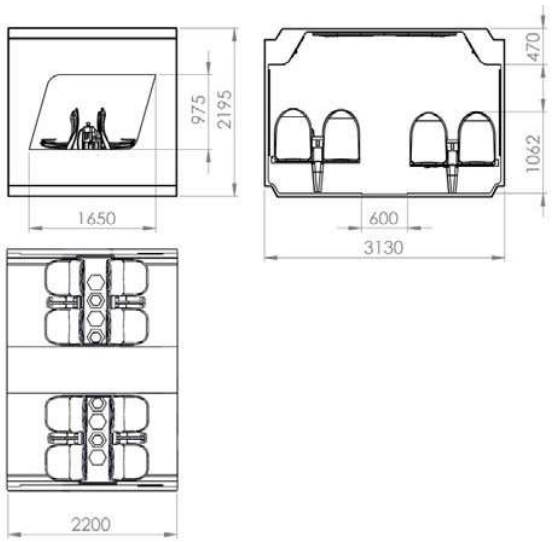

Fig. 7. Dimensions for the module for II class

The type 2 is similar to type 1, only the storage for luggage is placed between the seats (Fig. 8).

Fig.8 3D view of the module for II class, type 2

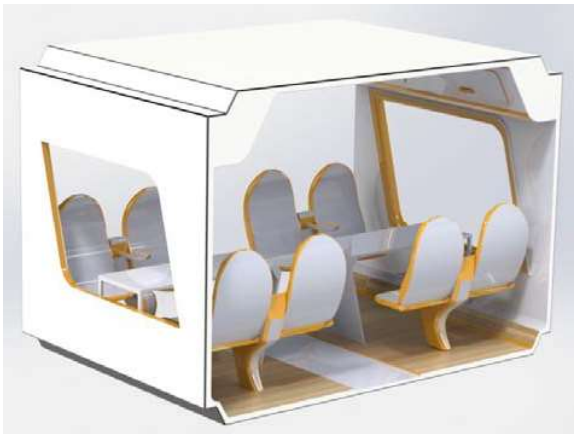

Fig. 9. 3D view of the module for II class, type 3

2 × 2 seats are facing each other, and between them is fixed table. Between the four seats is set the storage for luggage. The table has strict geometric lines, reduced to minimalism (Fig. 9).

The space for lighting and ventilation has clean, geometric shapes and simple lines that arouse futuristic vision versus everyday unfashionable spaces in today's buses and trains (Fig. 10).

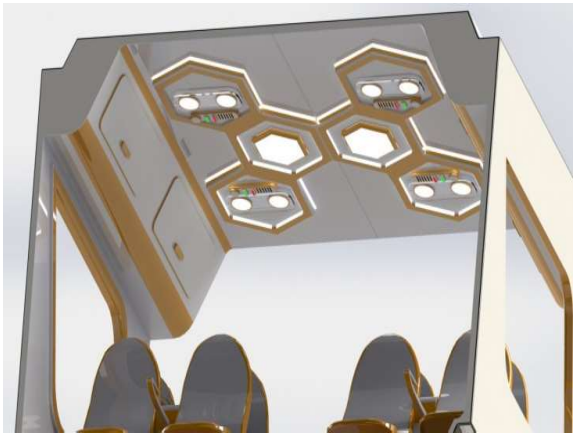

Fig. 10. Honeycomb shaped space for lighting and ventilation

A CONCEPT OF THREE-DIMENSIONAL MODULE FOR PESRONS WITH DISABILITIES

The layout and arrangement of the module for people with disabilities depend on accessibility, so it is placed next to the doors for easier entry and exit and easier and faster accommodation for the passengers in wheelchairs. The fixed seating on trains are designed according to international standards. Human factors and ergonomics are critical for providing adequate space in the area for a wheelchair. Although it is recommended that travelers use the seats on the train, they usually remain in the wheelchair who is facing forward or backward, but never on this side (Fig. 11). Technical drawings for the module for II class are shows on the Fig. 12 [2, 3, 9]

Fig. 11. 3D view of the module for the persons with disabilities

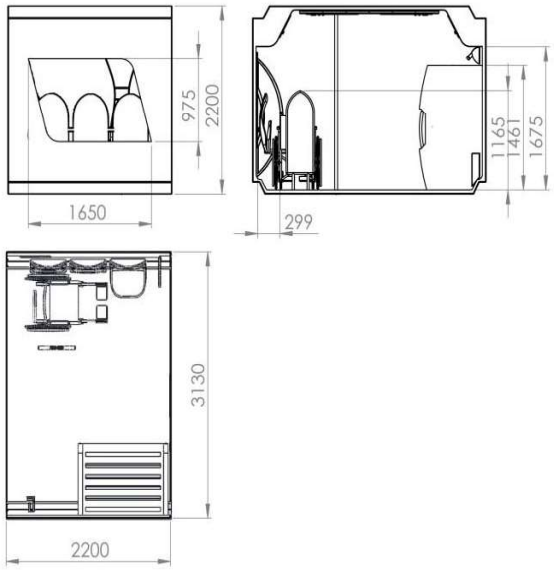

Fig. 12. Dimensions for the module for persons with disabilities

CROSS-SECTION OF A COACH

The intersection of combined modules for I and II class in the double-decker train is shown on Fig. 13.

By applying algorithmic design an algorithm it is developed which defines the layout of the modules in a coach. The main parameters that are entered are the length and width of the car, and the dimensions of the modules [7].

Fig. 13. The cross-section of the double-decker train (Module for I and II class)

The selected layout and combination of modules (Fig. 14), shows that one wagon has a capacity of 104 seats for passengers that:

– 36 in I Class, 56 in II class, 12 for disabled and infirm persons.

– Ability to store 4 bikes.

– Two toilets.

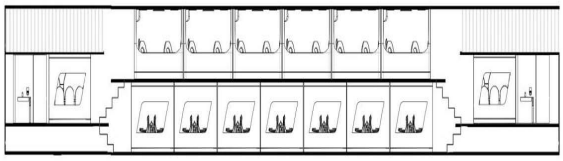

Fig. 14. Intersection of a wagon

ERGONOMIC ANALYSIS MADE WITH JACK PLM HUMAN MODELING

Jack PLM Human Modeling is computer software of the company *Siemens* specializes in 2D and 3D products. With the help of Jack several ergonomic analyzes are made that are crucial for the design of the interior of the passenger train. Most important of all is the early detection of possible defects before actual performance of the product and their correction in the design process. The preparation of the analysis began selecting anthropometric data (gender, nationality and percentile). Analyses were made by German human model of 5th female percentile and 95th men percentile [4, 5].

The created model can change its position depending on the need of research. In this project, the most important are:

– Seating comfort;

– Holding the handles;

– Easy movement and passing on the train;

– Easy and fast storage of luggage.

In an analysis the tool *Comfort Assessment* determine that the human model is positioned in a comfortable position in Jack. Based on various studies for comfort seating Tool Comfort Assessment:

• allow a choice from a list of six different studies of comfort, five based on a common point, and a study which analyzed comfort based on the whole body posture (Porter and Gyi, Krist, Grandjean, Rebiffe, Dreyfuss 2D and 3D*)* (Fig. 15).

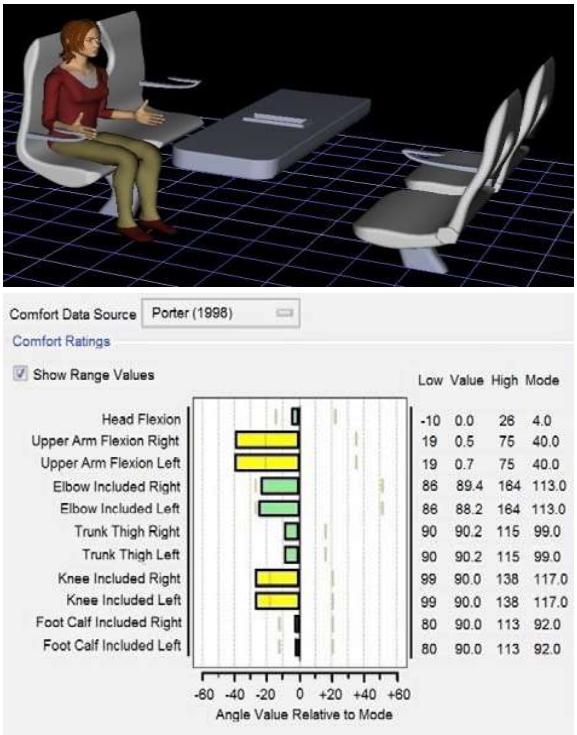

Fig. 15. Comfort analysis in Jack (Porter)

The analysis is performed by moving the human model to another position. The TSB analysis predicts the road required for the human model to achieve his goal. The road is represented using the red footprints in Jack scene (Fig. 16).

Ergonomic Report – TSB outcome of the simulation is the ability to automatically perform ergonomic analysis in real time. The results of the analysis to store luggage in class II, show the time in seconds required to perform the function and use of force by the body's muscles (Fig. 17).

Analyzes were made on the ergonomics of the holders, the use of the toilet and moving in the middle space in the module for second class. The results are displayed on Fig. 18 and Fig. 19. On the images can be seen that it is not necessary to change the measures in the design because it used anthropometric data and dimensions of space satisfying ergonomics.

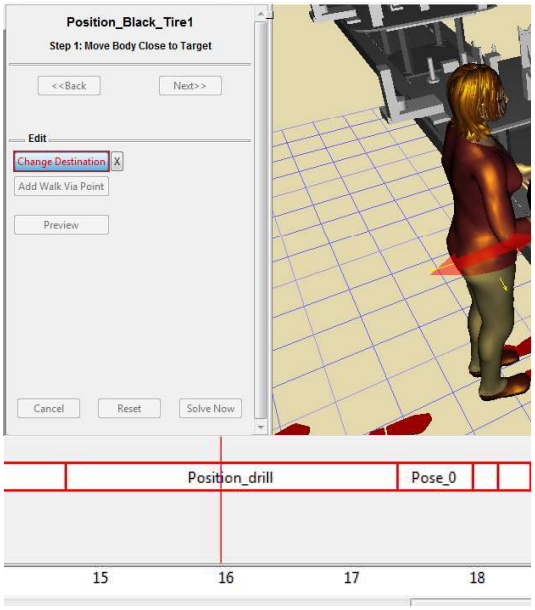

Fig. 16. Moving analysis from position A to position B in Jack

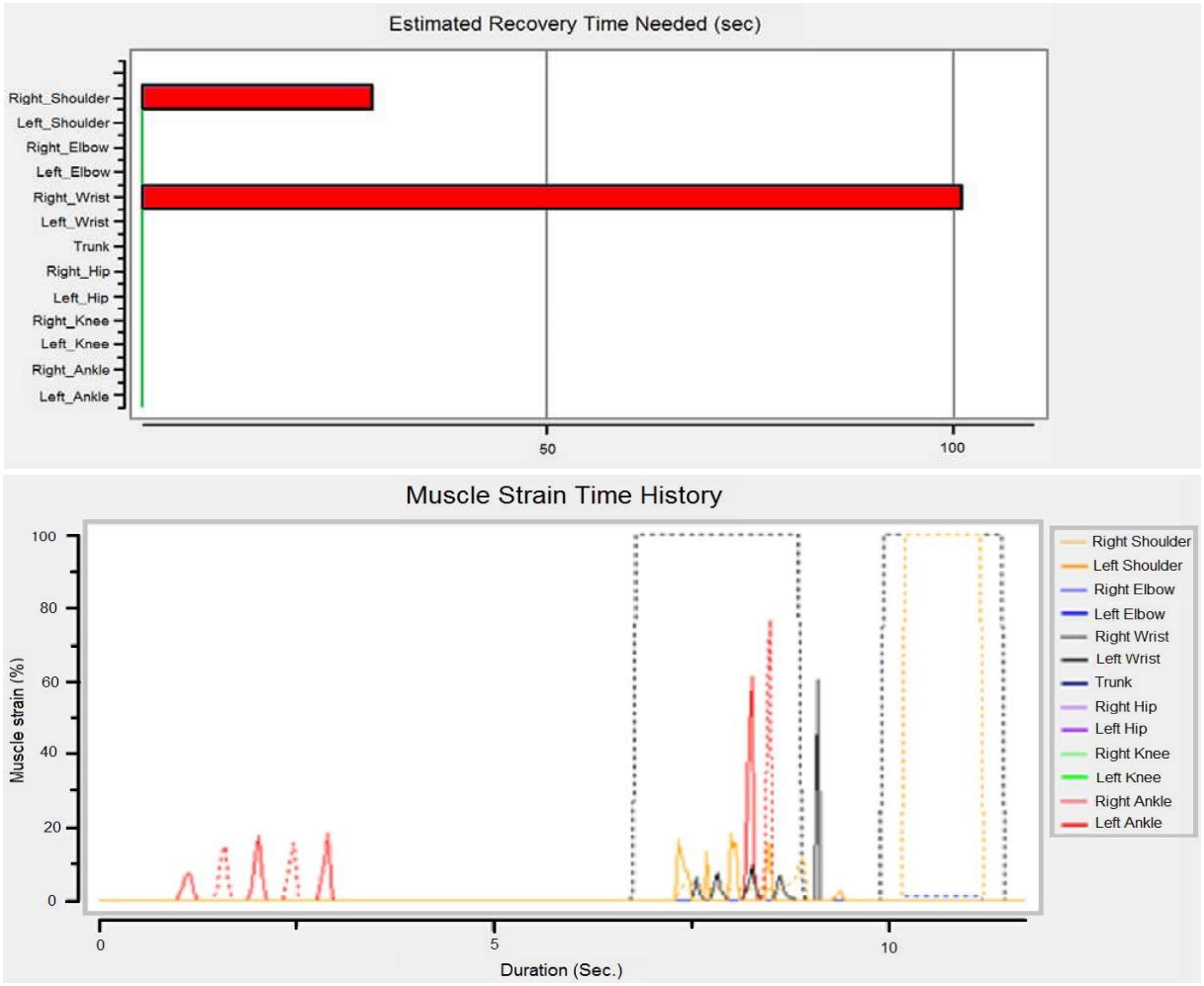

Fig. 17. Results of the analysis to store luggage in the module for II class in Jack

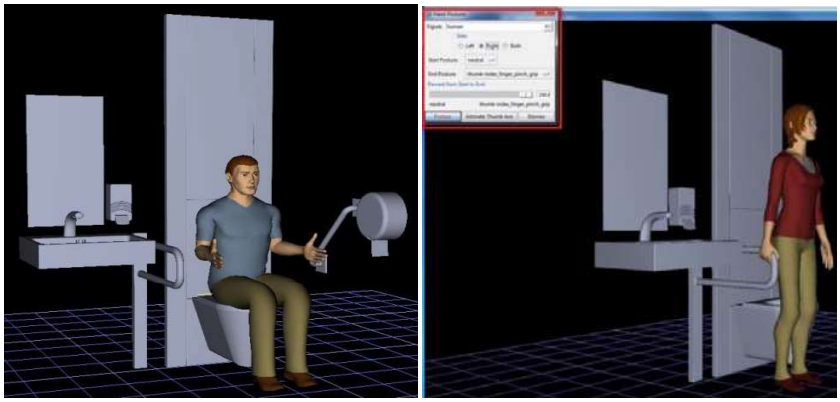

Fig. 18. Analysis on the ergonomics of using the toilet in Jack

Fig. 19. Analysis for easy moving in the middle space in the module for second class in Jack

ANALYSIS OF NATURAL AND ARTIFICIAL LIGHTING IN THE DOUBLE-DECKER COACH

Radiosity (3ds Max) is rendering technology that realistically simulates the way light works in the environment. Light levels in confined spaces – buildings, vehicles etc. is selected using the recommended level of brightness for different workspaces (Table 1).

Table 1

Recommended level of brightness for different workspaces

Activity	Lighting (lux, lumen/m^2)
Public areas in dark environment	20 – 50
Spaces for brief visits	50 – 100
Areas of work where only occasionally perform visual tasks	100 – 150
Warehouses, homes, theaters, archives	150
Easy office work	250
Normal office work, computer work, libraries, exhibition halls , laboratories	500
Supermarkets, mechanical workshops, offices	750
Drawing, detailed mechanical workshops, working in theaters	1,000
Detailed drawing, very detailed mechanical workshops	1500 – 2000
Perform visual tasks with low contrast and very small size of the longer period	2000 – 5000
Making a very long and precise visual tasks	5000 – 10000
Making a very special visual tasks with extremely low contrast and small size	10000 – 20000

For lighting the double-decker train is provided natural and artificial light or extra range 200–300 lux to perform normal activities – reading, simple computer work and activities related to entertainment and recreation, or watch movies, games and so on. The analysis of the brightness of the first floor of the double-decker train, designed to travel in first class is shown on Fig. 20.

The analysis of lighting is made as a result of the impact of natural light or solar radiation in summer time in 12 hours. It may be noted that due to lighting curved windows in the end zone satisfies the range 300–400 lux.

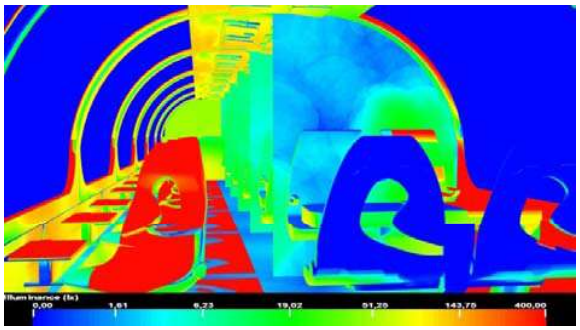

Fig. 20. Lighting analysis in the double decker train – I class with normal lighting in summer time in 12 pm

The analysis of lighting caused by artificial light (for each module 4 LED lamps measuring 25 W) shows that the tables are lit with 200–300 lux and hallway is lit with 300-400 lux due to the central placement of the lights because the rounded windows (Fig. 21).

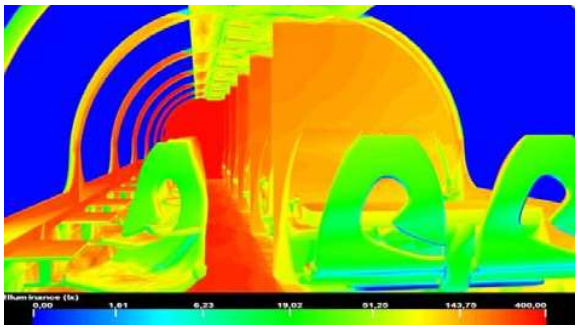

Fig. 21. Lighting analysis in the double decker train – I class with artificial lighting

An lighting analysis on the ground floor of the double-decker train, designed to travel in second class, the impact of natural light or solar radiation in summer time in 12 pm is shown on Fig. 22. It can be noticed that the lighting in the area of the windows where the sun's rays penetrate satisfies the range 300–400 lux, and in the opposite area to windows 50–100 lux. The orientation of the train is changing because its movement allows you to change these features. The analysis shows that the central part – the corridor should have more artificial lighting, although in certain times of day can satisfy the function for which it is intended.

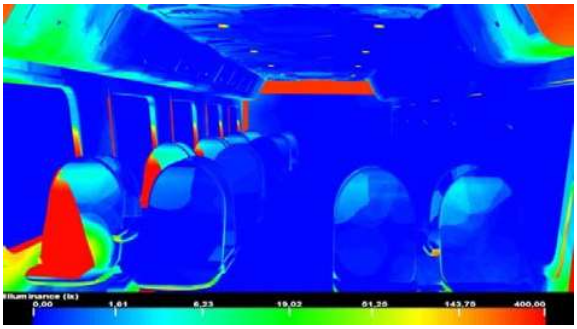

Fig. 22. Lighting analysis in the double decker train – II class with normal lighting in summer time in 12 pm

The analysis of lighting caused by artificial light (for each module 4 LED lamps measuring 25 W) shows that the sitting area is lit with 150–250 lux and hallway is lit by 250 lux. Seats which gravitate toward the hallway are well lit due to the positioning of the lights that are approximately over them (Fig. 23).

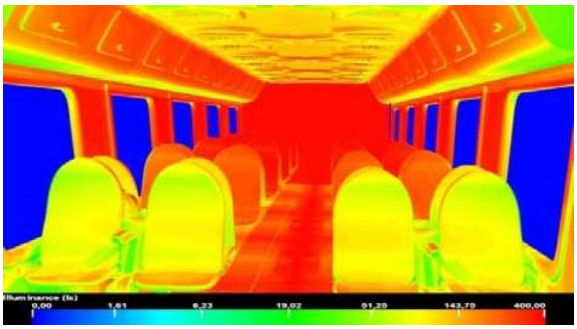

Fig. 23. Lighting analysis in the double decker train – II class with artificial lighting

CONCLUSIONS

This paper presents the concept of forming the interior with modules to build a double-decker passenger train. The shapes of the modules provide them easy and efficient coupling, multiplier flexibility in spatial displacement and possibility of recombination.

An ergonomic analysis is made with Jack PLM Human Modeling for comfort in sitting, holding the handles, movement and storage of

luggage. The results showed that the problem with ergonomics is solved and the new design offers comfort for the passengers. Analysis of natural and artificial lighting in the area is done in Radiosity (3ds Max), which actually simulated the way light works in the environment.

REFERENCES

[1] Agkathidis, A.: *Modular Structures in Design and Architecture*, BIS Publishers Amsterdam and the editor / authors, USA, 2009.

[2] Bradtmiller, B.: *Anthropometry for Persons with Disabilities: Needs for the Twenty-First Century*, Resna Press, USA, 2005.

[3] Tyrell, D., Severson, K., Marquis B.: *Analysis of Occupant Protection Strategies in Train Collisions*, U.S. Department of Transportation Cambridge, USA, 1995.

[4] Neufert P. and E.: *Architects' Data,* Third edition, School of Architecture, Oxford Brookes University, Oxford, 1999.

[5] Dreyfuss, H.. Alvin Tilley, R.: *The Measure of Man and Woman: Human Factors in Design*, Wiley Publishing, USA, 2002.

[6] Fresco, J.: *Designing the Future*, *The Venus project Inc.,* Venus, USA, 2007.

[7] Terzidis, K.: *Algorithms for Visual Design Using the Processing Language*, Indianapolis: Wiley Publishing, USA, 2009.

[8] Leander, P., Meyer, T.: *Eurotrains – a concept for passenger trains of the future*, The Community of Nordic Railways, Norway, 1996.

[9] Sestranetz, R., Adams L.: *Free Movement* of *People* with *Disabilities* in *South East Europe,* Disability Monitor Initiative, Serbia, 2006.

[10] Nachtigall, W.: *Bionics, Principles and Examples for Engineers and Scientists*, Springer Verlag, Germany, 2006.