APPLICATION OF LIFECYCLE ASSESSMENT AND FINITE ELEMENT ANALYSIS IN THE DESIGN OF RAISED ACCESS FLOOR PRODUCTS

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Key words: Finite Element Analysis, Lifecycle Assessment, Raised Access Floor Product Sustainable Design, Product Design

Abstract: In this research, lifecycle assessment (LCA) and finite element analysis (FEA) are applied in raised access floor product design. LCA is conducted to assess the product's sustainable features, while the FEA is carried out to ensure that the product meets the required strength. The materials used to develop the floor panel is Sheet Moulding Compound (SMC) with 30% glass fibres. The product is modelled in SolidWorks software package. Based on the CAD model of the product, the LCA and FEA are then conducted. The LCA results revealed that the materials contribute significant impacts in the four environmental impact categories: 84% in carbon footprint, 91% in total energy consumed, 73% in air acidification, and 66% in water eutrophication. The LCA evaluation results not only clarify the optimized design targets, but also enable to benchmark values for design iterations. According to the FEA, the deformation values are less than 2.5 mm with 3000 N loading forces on the central of the panel and stringer, which meet the flooring product's deformation criteria of Class A, as defined by the British Standards.

1 INTRODUCTION

A typical raised access floor comprises of load bearing floor panels laid in a horizontal grid supported by adjustable vertical pedestals, which provides an underfloor space for the housing and distribution of services in a building. The floors generally consist of 600mm X 600mm panel supported at each corner by pedestal jacks, each jack locating and supporting the corners of four adjacent panels. A raised access floor product system is shown in Figure 1. The floor panels are readily removable to allow quick access to the underfloor services. The adopting raised floor products provide flexibility in the design and layout of telephone, electrical, electronic communication cables and air-conditioning systems, which are easily routed below the floor panels.

The materials to make the floor panel normally includes particle board, plywood, aluminium, steel, or a combination of metal and non-metal. The particle board or plywood panels are usually covered with thin sheet steel or aluminium for implementation of fire protection. In some cases the steel is in the form of a tray, depending on the bonding adhesive used between the wood product and the steel, it can increase the structural strength of the panel. SMC (Sheet Moulding Compound) materials are used for producing the floor panel in this project, because of its strong performance in mechanical properties, fire resistance, and stiffness. The physical properties of the selected SMC material are presented in Table 1.

This paper presents a computational approach to develop this floor product system. The approach include 3D CAD modelling, lifecycle assessment (LCA) and finite element analysis of the product (FEA).

Figure 1: A generic raised access floor product system [1]

Table 1: SMC physical properties

properties	values
Density of the selected SMC	1800 kg/m^3
Flexural modules	1.3 GPa
Poisson's ratio	0.3
Yield strength	250 MPa
Tensile strength	150 MPa

2 INITIAL DESIGN AND MODELLING

The modelling of the raised access floor system involves the design of a floor panel and pedestals, as shown in Figure 2. The standard size (600 mm x 600 mm x 40 mm) is applied for the raised access floor panel in this project. The dimensions of the design prototype are presented in Table 2, which meet the criteria of the British Standard 12825 [5]. The pedestal design prevents excessive movement of the panel, by which the stability of the raised access floor system is enhanced.

Table 2: Dimensions for the initial design

Component dimensions of raised flooring product	
items	**values**
Height of pedestal	100 mm
Square base plate	100 mm x 100 mm
Diameter of circular plate at the top	90 mm
Size of the floor panel	600 mm x 600 mm x 40 mm
Weight of the floor panel	25.92 kg

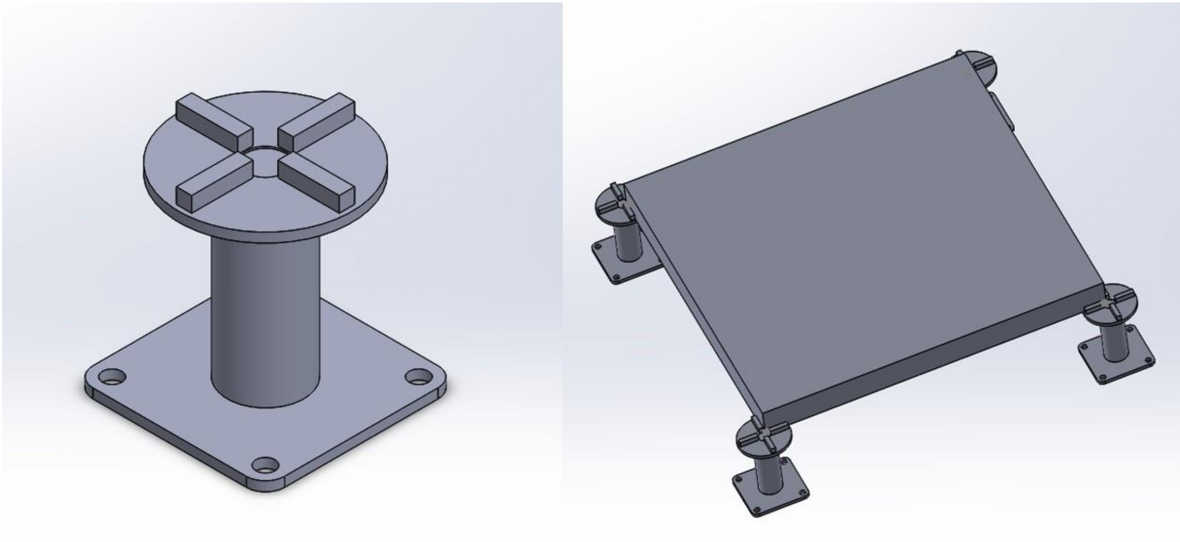

Figure 2: Initial design for the pedestal unit (left) and the raised access floor system (right)

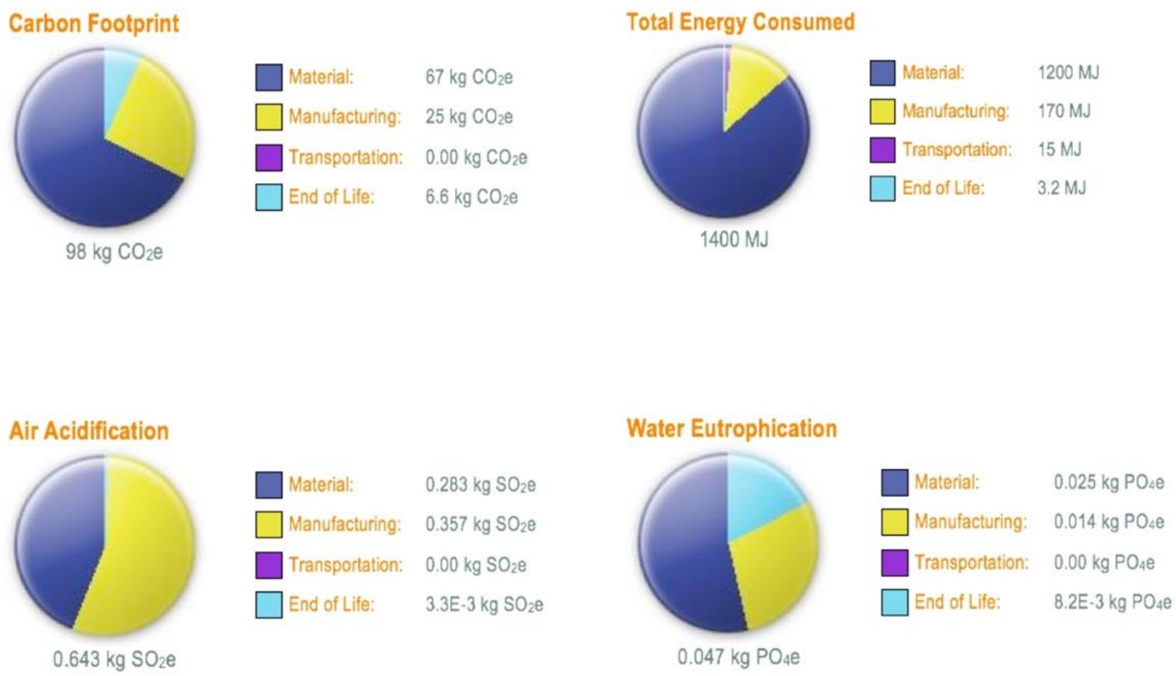

Figure 3: The LCA results by applying CML methodology in SolidWorks 2015

The weight of the floor panel is 25.92 kg, which is obtained by calculating the design dimensions and SMC density. This is much over the weight, 11 kg, of the existing product in the market with the same size and made of chip board covered by metal sheets. And hence re-design has to be considered in order to reduce the weight.

CML and TRACI are LCA based methodologies, which are embedded in the sustainability package of SolidWorks 2105. The CML method is applied in this phase, and the results show that the materials contribute major negative impacts in the four environmental impact categories: 84% in Carbon Footprint, 91% in Total Energy Consumed, 73% in Air Acidification, and 66% in Water Eutrophication. The pie chart of the LCA analytic results are presented in Figure 3.

3 RE-DESIGN

According to the initial design, the floor panel is over-weight. Therefore, reducing the weight of the floor panel is the prioritized task in this phrase. In addition, necessary LCA and FEA have to be conducted in order to ensure the product meets the required functions.

3.1 Refinement of the raised access floor system

In order to achieve an effective design, the floor panel requires strong outer edges with the side of the panels connected by ribs, hence, the strategy of designing ribs for the floor panel is confirmed. The optimum design of the floor panel has same size squares with 3 mm ribs between them, and the layout and dimensions of these squares are shown in Figure 4 and Table 3, respectively.

Table 3: Main components' dimensions and weight in detail design phrase

Component dimensions and weight in detail design	
Items	**Values**
Square	94.7 mm X 94.7 mm x 94.7 mm
Thickness of ribs	3 mm
Thickness of the floor panel	30 mm
Size of the stringer	600 mm x 600 mm x 37 mm
Thickness of the string edge and beam	3 mm
Component weight for detailed design	
Items	**Values**
Floor panel	3.52 kg
Stringer	3.55 kg
Pedestal unit	0.99 kg
Total mass	8.06 kg

The thickness of the floor panel is cut from 40 mm to 12 mm in the design comprising rectangles' size and ribs' thickness, therefore the strength performance of the floor panel is reduced. The solution of placing a steel stringer under the floor panel is employed, as this design not only sustains the strength performance of the floor system, but also provides the facility of recycle or reuse for the steel stringer. The stringer design is shown in Figure 4, and its dimensions are shown in Table 3. With this optimum design, the total weight of this raised access floor system has been reduced to 8.06 kg, which is lighter than the average weight of a raised access flooring product. The refinement of the raised access floor system is presented in Figure 4.

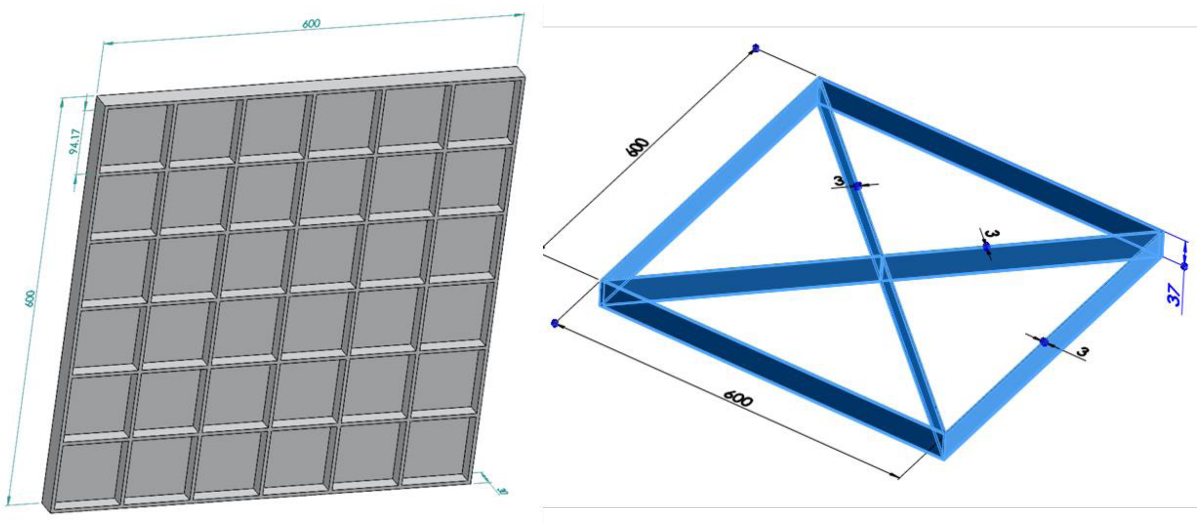

Figure 4: The design of the floor panel (left) and stringer (right) in detail design phrase

3.2 LCA of the raised access floor system

LCA is conducted in order to assess the product's sustainability, and, in particular, to identify the environmental impacts of materials and manufacturing processes, which will enable to set up optimization strategies for design and production process optimisation.

3.2.1 LCA modelling

Considering the available data and objectives of this research, the examined life cycle processes of the raised access floor system include: Materials, Production, Distribution and End of Life, which are described as follows:

Materials: The main ingredients of SMC are glass fibre and polymers. The pedestal unit and stringer are manufactured with normal steel. The floor panel is packaged with wood pallets and PVC films

Production: The examined processes of producing SMC include: heating of resin and moulding, which follows the information of the SMC product specification [2]. The examined processes of producing the floor panel include: heating, cutting ribs and edges. The examined processes of producing the pedestal unit and stringer include: extrusion of steel, and steel turning. The main process not covered in this phrase is the production of glass fibre, which usually include raw material extraction, glass melting and refining, and fibre forming and finishing [3].

Transportation: The examined distribution scenarios are from manufacturing site to retailers or construction sites in England, and this distance is an average of 200 km (suggested by the floor panel prototype manufacturer). The neglected distribution scenarios are the delivery of SMC ingredients from suppliers to manufacturers, and the delivery of packaging materials from suppliers to flooring product manufactures.

End of Life: This study refers for the waste treatment and management figures in England that are provided by the UK DEFRA [4].

3.2.2 Lifecycle impact assessment (LCIA) results

The environmental impact assessment of the raised access floor system is carried out using SolidWorks 2015 with CML method. The assessment results are shown in Figure 5.

As revealed in Figure 5, within the total impacts, the major negative impacts are generated by the Materials (80.6%) and the Manufacturing (13.6%). The Transportation and End of Life share the 0.6% negative environmental impacts within the Carbon Footprint impact. Within the Total Energy Consumed, Materials cause 74.5% energy consumption, and Manufacturing steps have 25% consumptions, and the Transportation and End of Life total share 0.048% consumptions. Within Air Acidification impact, the Materials have the major impacts (59.2%), and Manufacturing cause 37.9% impacts. The impacts caused by the Transportation and End of Life are 2.79%. Within Water Eutrophication impact, Materials, Manufacturing , and Transportation and End of Life cause 68.7% , 9%, 3% and 17% impacts, respectively.

Compared with the environmental performance evaluation results between initial design and re-design, the four environmental impacts with CML methodology, Carbon Footprint (10.2%), Total Energy Consumed (29.2%), Air Acidification (67.2%), and Water Eutrophication (31.9%) have been improved. This shows the optimum design have achieved, which performs improved environmental impacts while meets the quality and requirements of the floor product standards.

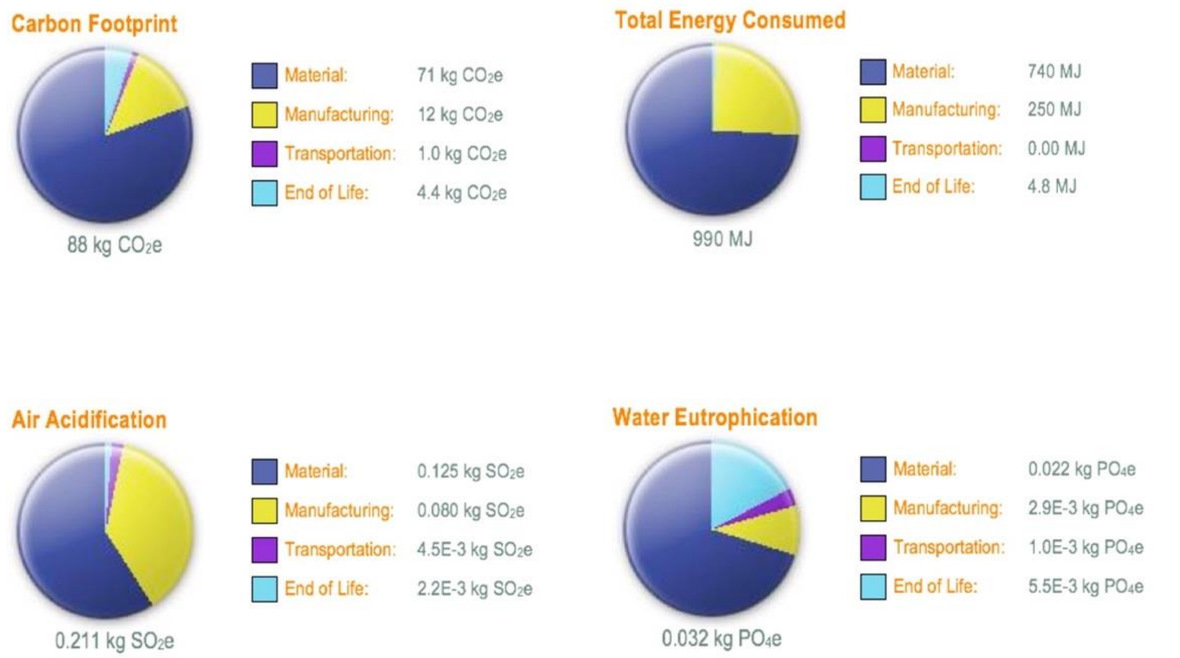

Figure 5: The LCA results by applying CML methodology in SolidWorks 2015 for the improved design

3.2.3 Analysis of the results

As the End of Life and Distribution share relatively small negative impacts in the life cycle of the raised access floor system, the target of design improvement should be placed at the Materials and manufacturing. The following strategies are proposed to achieve this objective through exploring the findings of the LCIA.

The mass of negative impacts caused by the main flows within the three environmental impact categories, which could be used as benchmarking values in the next iterations of design. For example, in the case of investigating alternative main materials, the total mass of negative impacts can be used as the key benchmarking value to examine the potential material's environmental performance.

The Materials has the most negative impacts, and the Distribution stage has the smallest negative impacts, which proves the design improvement strategy on reducing the mass of materials is correct, and in order to achieve further design improvement, the design on the ribs and rectangles of floor panel could be elaborated, for example, reducing the thickness of ribs, or increasing the depth of each rectangles.

The Injection moulding process causes the highest negative impacts among all the production processes, so an improvement strategy would be to cutting the overall moulding cycle time, and improve the mould speed.

4 PROTOTYPING AND TESTING

4.1 The prototype

In this phase, the prototype of the raised access floor system is manufactured and analysed to confirm that the product meets the required environmental impact and strength. The prototype of the raised access floor system is shown in Figure 6. The fire safety test must be conducted under controlled conditions, and by an external fire safety test company, which is not reported in this paper. The following section is to report the Finite Element Analysis for the floor product prototype.

4.2 Finite element analysis

Finite element analysis module of SolidWorks 2015 is used to assess the strength of the product in this phrase. With the FEA results, the relationship between the force and deflection of the floor system can be identified.

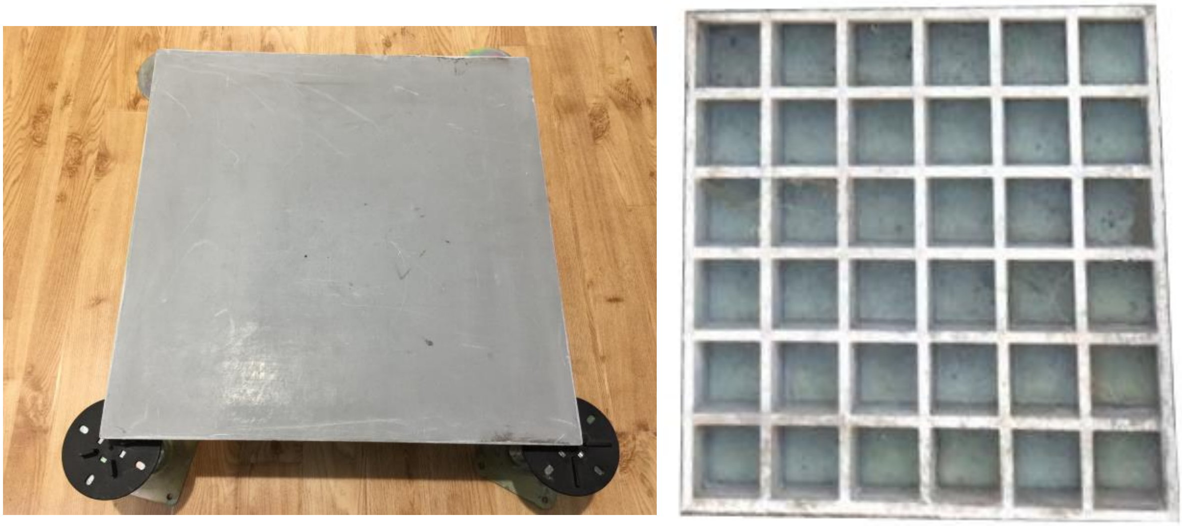

Figure 6: The prototype of the raised access floor product system (Left) and the back of the floor panel (right)

Two key indicators for FEA are maximum yielding stress (von Mises stress) and maximum deformation. According to the Fourth Strength theory of material mechanics, the flooring product starts to yield at a location when the maximum yielding stress becomes equal to the yielding strength, which is the upper limit of yielding stress. For the flooring product developed by this project, the yielding strength is obtained utilising the physical properties of the floor panel and stringer. The maximum yielding stresses of the panel and stringer are required to be less than 94MPa and 250MPa respectively, while the maximum deformation of the panel and stringer should be lower than 2.5mm. According to the requirements of British Standards BSEN 12825:2001 [5] and Platform Floors (Raised Access Floors) Performance Specification [6], 3000 N working loads are required to place at the centre of the floor panel.

As Figure 7 shows, the deformation values are less than 2.5 mm with 3000 N loading forces on the central of the panel and stringer, which satisfy the flooring product's deformation criteria of Class A, as defined by the British Standard requirements. Therefore, under 300 N of working loads, the designed flooring product is able to work properly within the scope of elastic deformation.

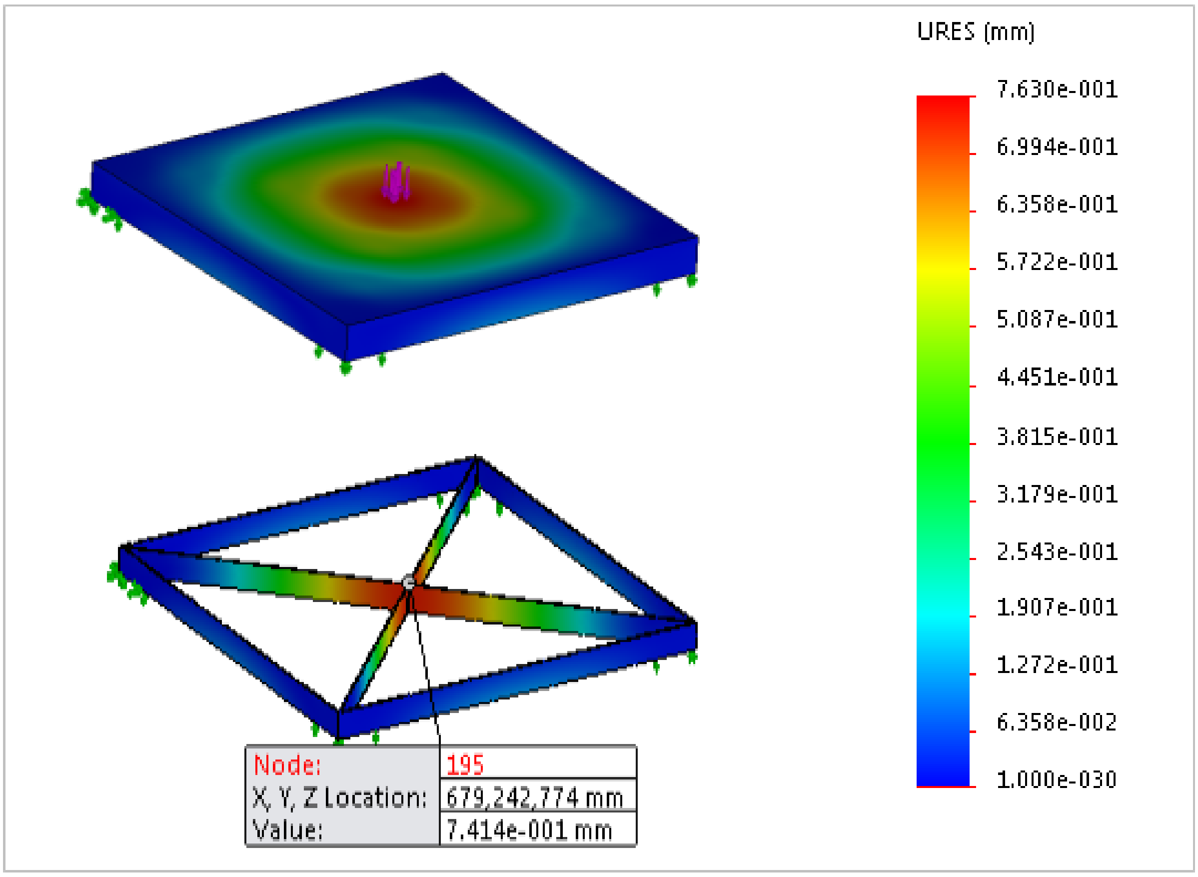

Figure 7: Max deformation for the floor panel and stringer with loading 3000N forces at the centre panel

5 CONCLUSIONS

A new type of raised flooring product is developed, which consists of a rib-supported floor panel made of SMC materials, a metal stringer and pedestals. 3D CAD modelling, LCA and FEA were conducted. The assessment results confirm that the product meets required LCA and FEA performance.

The floor panel has achieved 44% weight reduction compared with the traditional raised access floor panel. The prototype passed the strength test and met the environmental requirements stipulated by the regulations and standards on manufacturing floor products in the EU and UK market. CML methodology and SolidWorks software are applied to evaluate the life cycle environmental performance of the flooring product, the results show that the major environmental impacts are related to the SMC material and manufacturing process.

ACKNOWLEDGEMENTS

The authors acknowledge the research grant received from the Ministry of Science and Technology, China (Grant No. 2015DFA51330), which supported the research presented in this paper.

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