COMMONALITY OPPORTUNITES OF ALUMINUM EXTRUDED PANELS ACROSS DIFFERENT VEHICLES

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1. INTRODUCTION

Currently, there is an increased amount of electric buses, buses driving on dedicated lanes and there are metro cars which ride on tires [1]. Differences between traditional rail vehicles and road vehicles are not as distinguish as it used to be. Bus electrification is visible because it allows reducing fuel consumption and decreases the environmental footprint [2], [3]. Such situation is caused not only by good intentions of manufacturers and users, but as well by strict regulations. The emission limits for vehicles are very low, Euro VI standards reduced emission limits for NOx several times and particulate matters PM emission for more than double compared with Euro IV standards [4].

There are few manufacturers that produce both types of vehicles, buses and light rail vehicles. Those manufacturers include Bombarider, Siemems, and Solaris among the others [5]. During the case study conducted in one of the manufacturers and presented in this paper, it turned out that potential benefits coming from sharing components between different products are not realized. Other manufacturers most likely also don't maximize benefits because different company divisions are responsible for development and manufacturing of parts designed for different products. A great problem for any manufacturer is the engineering effort necessary to produce every set of products for a particular client. Depending on the area of the world in which buses or railway vehicles will be used, design requirements for the same type of vehicle change. Moreover, specific climate may require additional equipment such as heating or air-conditioning. One of the solutions for a manufacturer is to use common components in locations not visible for customers and customized elements for product differentiation. Commonality is an approach of calculated reuse of parts in different products [6]. Such approach provides a mechanism for bringing products to market faster: by a development of robust product platform architecture with common components [7]. Commonality increases quality, prevents resource waste, decreases costs and, most importantly, decreases total development time of the product by eliminating unnecessary development steps of individual components [8]. A major commonality step is to look for parts with different designs, but the same function. This may provide an idea of possible optimization opportunities and selection of the most suitable design that can be common across a few products. After a detailed analysis of the car body shell (CBS) components in the light railways and trams, it turned out that there are parts that can be potentially common. The most interesting elements for further study were floor and roof panels. There is some literature proposing different solutions for lightweight

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floor and roof panels such as honeycomb, and sandwich composite solutions [9], [10]. In the case of aluminium CBS, extruded profiles are the most common solution. Our hypothesis is that number of profile solutions solution may be reduced and common not only across different rail vehicles, but as well buses. The majority of buses are made from steel bars welded together [11], [12]. Light rail is more shifting towards aluminum usage for structural parts. Aluminium has been used in customers vehicle construction more than twenty years, however, its use in buses has been limited. Aluminium, is expensive, joining and forming technologies make the application more difficult than steel [13]. Aluminium apart from lightweight is also non-flammable and doesn’t generate hazardous gases which make it a preferable material for applications in flammable or explosive situations in comparison to lightweight honeycomb solutions [14].

Since extruded profiles with C-rails occur in most of the aluminum platforms, when we optimize their weight and strength and make it common, we will be able to make improvements in many locations at the same time. Selected panels and interfaces were analysed by numerical simulation in order to evaluate their mechanical behaviour.

Many railway car manufacturers make their floors and roofs from a few long aluminium extruded panels that are later welded together. Such a structural assembly supports multiple equipment attached to it in a variety of ways. During CBS analysis, it turned out that those critical elements often have different designs depending on the train type within they are used. Even on one coupled vehicle, many different panels were used because of the variety of equipment. Final assembly of those panels is relatively heavy, that allows for potential weight reduction after optimization.

The key problem this research paper investigates is commonality opportunity of reusing the same design for aluminum panels in different light rail and bus applications. Long extrusion is a specific process that takes a long time to set up for final production. Commonality of the aluminum panel concept across different product could lead to decreased development and manufacturing time, and reduce cost. If a panel concept could be used across a variety of platforms, many weeks would be saved during the development phase. The same tooling could be used during manufacturing and production would be made in larger batches. That’s why tis paper present efforts that need to be undertaken in order to make parts common across different products.

2. SELECTION OF COMMON PARTS

Increasing the number of common parts not always bring desired benefits, that is why it is important to focus on execution and selection of correct parts for commonality [15]. There should be some method, rule, or criteria in order to decide which components to make common. From a commonality perspective, the components that have high design costs and require a high amount of redesign effort should be focused on first. Moreover [16] also emphasizes that commonality is not only used by mass production, but also by mass customization companies. Companies producing mass customized products fix the base product design and later on a family of variants is made. Companies that have multiple products in their product portfolio, in theory, should look for ways to reuse design information from one order to the next, but many times such opportunity is lost [17].

3. CASE STUDY

In this research a commonality methodology that allows manual search for commonality opportunities was used. This case study was conducted on the European manufacturer, which produce railway and bus products. The first step was to list all existing interfaces and CBS elements. By doing so, it was possible to select the most frequent solution. Such an approach allows for affecting the largest amount of solutions at the same time. It can be predicted that, by doing so, development time could be reduced. Extruded profiles with C-rail are widely used across all of the train platforms, including tram and light railways, as floor or roof profiles. In buses such a solution did not exist, but there is an on-going research and development of a lightweight bus, which potentially could use the same concept. Extruded profiles with C-rail have the same function, but different designs. All panels are used to support different types of equipment or passengers. C-rail solution provides a flexibility which type and size of equipment can be mounted. There are big differences profile designs in the manner of dimensioning, shapes, C-rail type's locations in relevance to a whole floor (or roof), and in relevance to the profiles inside webs. If it would be possible to select a concept that could be common, then significant reductions in development time would be achieved, as well as the reduction in manufacturing cost. Final extruded elements can take up to 40 weeks to be ready for manufacturing. Savings in a development time could give big competitive advantages.

In order to have comparable results, all of the panels were adapted to have the same height and length. The main difference between analyzed panels was the location and shape of inside webs. The first step was to create a base model of interface connections that later would be the same in all panels. This allows for the understanding of the behavior of the interface system and, further, its influence on whole panel structure. Also, it will allow using different length op panels to be used in buses and railway products. Next, panel cross-section cuts were adapted to be comparable and meshed. This step allows comparing local characteristics of different design variants. The last step was to model entire floor panels that allowed having a global perspective of panel behavior under multiple loads. When critical issues are addressed during the initial phase, then further costs of expensive testing and design changes can be reduced [18].

3.1 Initial model of panel sections with C-rail interface

The model was simplified drawing of three panels used by company and one additional panel developed in CATIA v5. The finite element method (FEM) numerical simulations were performed using the nonlinear commercial finite element software Hyper Works v12 [19]. Three dimensional mesh elements were used for this model in order to be able to observe results in all directions. All of the components were meshed with quad element walls, with no tetra mesh being used. Mesh element size was the smallest utilized in C-rail because this was the component in which failure was predicted (high stresses in C-rail corners). All materials in the model are MATS1 (defined in Hyper Works as Stress-dependent Material Definition); C-rail and Profile are aluminium while the bolt was from stainless steel. Material properties were imported from a table of aluminum 6xxx series, in order to include the stress-strain curve, and were assigned to components.

The first model created was a squared panel with vertical webs and the initial model of a C-rail interface. The second design was a panel widely used among different railway platforms based on triangulations of webs (inside part of extruded profile). The third design was a variation of triangulation in which webs are speeded apart in order to join with the flange (horizontal parts of panels) in the location where the C-rail begins. The fourth design used a three web panel with an inside C-rail. All of the design variants and previously meshed models of the four profile sections used for the study can be seen in Figure 1.

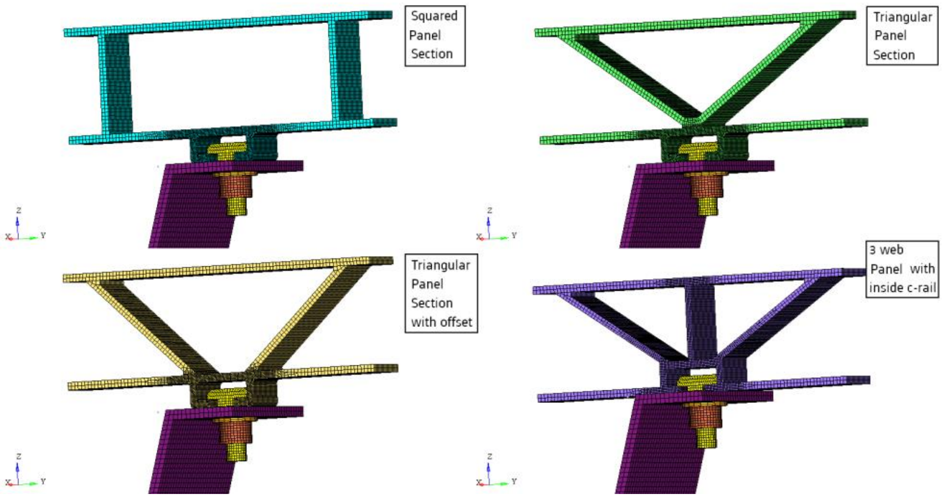

Figure 1 Meshed models of four profile sections used for study

In order to get comparable results from the panels, global dimensions were adapted so that all models had the same height, (along the z-axis), width (along the x-axis) and length (along the y-axis), without taking into consideration the C-rail. Boundary condition BC1 was shifted to the end of the panels along the x-axis. The solution with the inside C-rail was a potentially interesting solution in terms of small dimensions, the possibility to increase cabin volume. Moreover inside C-rail leaves the flat surface, which increases the flexibility of use.

3.2 Simulation of floor panels made from profiles with C-rails

As a last step in the panel analysis, a simulation of assemblies made from panels with an inside C-rail was conducted. Four panel assembly models based on the panels presented in figure 2 were made, but with extended width and length now close to the dimension of the average panels used in vehicles. Those panels were used not only for further simulation, but also for weight comparisons. Figure 2 presents an example of a triangular panel with offset, which is one of five simulated panels.

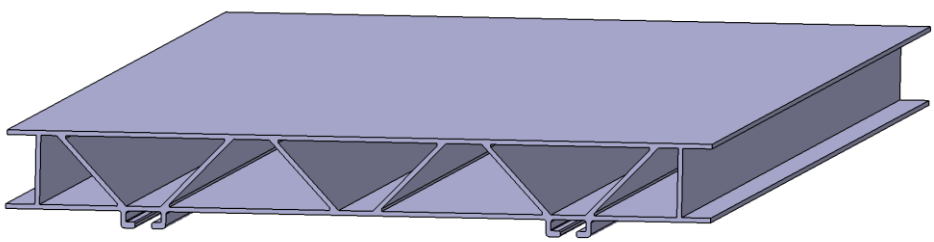

Figure 2 CAD model of floor panel used for weight calculation, and after meshing for floor simulation

Usually, a train floor is made from 5 panels. The overall dimensions of the train floor depends on the model but, for the simulation, 9 meters (length) x 2 meters (width) x 50 mm (height), subject to the boundary conditions and the distributed pressure load with 6 persons (each 70 kg) / m^2. Such dimensions are actually in use in railway application and potentially allow usage of the same panels in bus application. To maintain symmetry conditions, only half of the width was modeled, using two and a half panels. In order to decrease calculation time, 2-dimensional mesh and shell elements, in order to assign thickness to the web and flange, were used.

3.3 Results

A file generated by HyperMesh and later modified was uploaded to Optistruct, which is a solver program. Among many possible outputs, displacement, contact pressure, and stresses were further analysed. The first analysis was concerned in order to check under which load would the interface start to lose tightness, which will lead to a loose connection. The gap opening between C-rail and profile represents the loosening of the interface connection. The load applied on the interface was gradually increased until it reached the point in which gap opening occurred. Gap opening was measured in micrometres, a very small unit of measure, but it represents the initial phase of opening, or loss of contact pressure, which is proof that the connection will start losing tightness at that particular point. Figure 3 presents the area in which gap opening was measured between the C-rail and profile. The locations of the measuring points were on the side of the applied load below the T-bolt head.

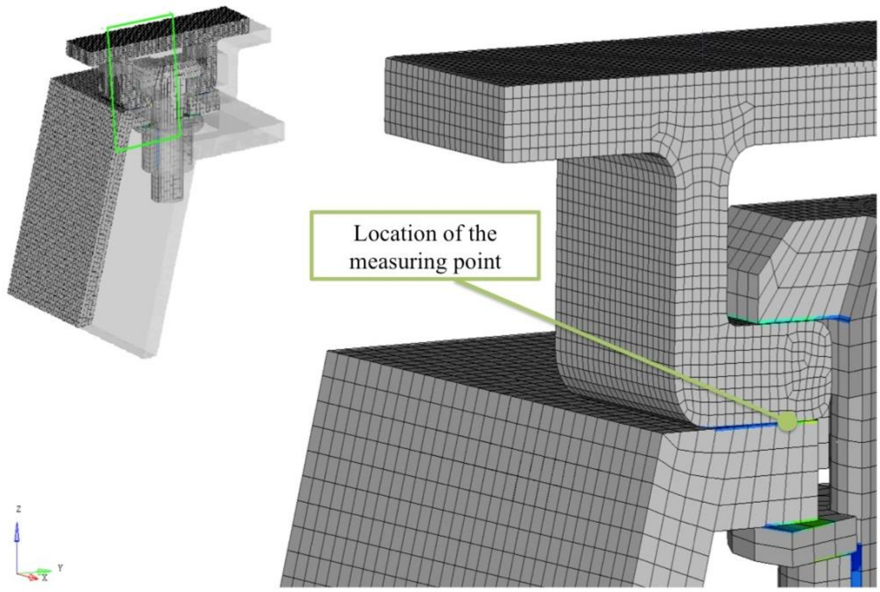

Figure 3 Global and a detail view on the area in which gap opening was measured. The square adjacent to the global view indicates the area selected for the detail view.

Such an interface can withstand loads up to 1288 [N] load, which comes from a multiplication of 3g by 175kg and dividing it among 4 supports. The maximum value of stresses does not change significantly after applying only pretension and adding load, but the locations of stress concentrations change. It is possible to observe that compressive stresses are higher in C-rail, and tension stresses are greater in T-bolt.

Results show that under the same load, all panels with an outside C-rail have the same gap opening of 0.001 [mm]. Most interesting is the fact that the panel with an inside

C-rail produced a greater gap opening of 0.003 [mm]. Panels with an inside C-rail have the least tight connection, and it is possible that the load interface will become loose.

The second result analyzed was displacement under the same load. Squared panels have the greatest displacement in the Z-direction among the simulated panels. The original triangular panel and the triangular panel with offside exhibit a very similar behavior. The profile with an inside C-rail has the smallest displacement and the best flatness of the top flange surface. This panel is the stiffest solution, which explains why the gap opening is greater under the same load than in panels with an outside C-rail. In panels with an inside C-rail, the mounting profile shows deformation because the panel is not "working." In other words, the panel elements are not deforming. For panels with outside C-rail flanges and webs, all components absorb part of the load by their deformation. This allows the outside C-rail to be in longer contact with the profile.

Comparison of ZZ stresses in four analyzed panels is presented in Figure 4. A T-bolt was used in all calculations, but it is removed from the visualizations in order to present the stresses in the C-rails. In all four cases, the highest stress concentration is in the C-rail, but the magnitude and exact locations vary depending on the panel type. In the case of the squared profile, there are also high stresses in the panel web. This is why, in Figure , we can see a larger view on the squared profile and a more detail view on the C-rail in the other simulations. In the case of the triangular profile, there are also stresses in the bottom joint between the web and flange, which can be seen in Figure 4.

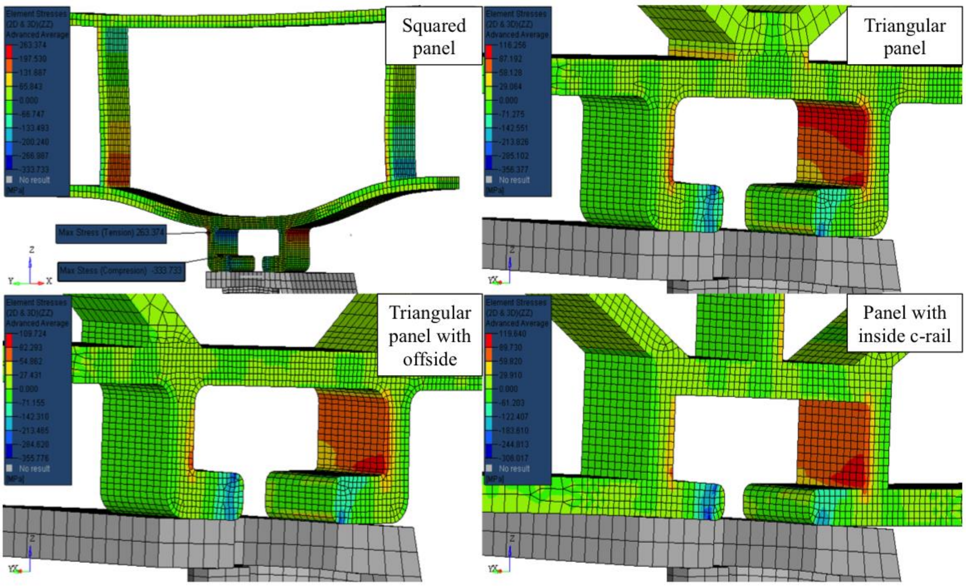

Figure 4 Comparison of ZZ stresses in four analysed panels. T-bolt used in simulation, but removed for clarity of view

Highest negative stresses (compressive) can be found in the triangular panel and in the triangular panel with offside in the place where the T-bolt is located. In all cases, the value of compressive stress exceeded the plastic limit as was seen in the primary model. Highest positive stresses (tension) can be found in the squared panel, and it is the only model in which tension stress exceeds the plastic limit, thus causing permanent deformation.

The last part of the results involves whole panel simulations. Figure 5 presents results of the displacement of half of the floor made from panels: the top floor is made from a panel with an inside C-rail with 3 webs and the bottom floor is made from a panel with a triangular web with offset. The profile with inside C-rails has displacement which is not acceptable according to initial study requirements. Because of its properties, panels with an inside C-rail are not advised to be used in an underframe. This solution is only advised for roof interfaces with lightweight equipment. On the roof, the requirement is to withstand equipment weight and support the weight of one person with a toolbox. Floors made from panels with an outside C-rail or triangular webs with offside passed deflection constraints which show that both panels can be used as underframes and roofs.

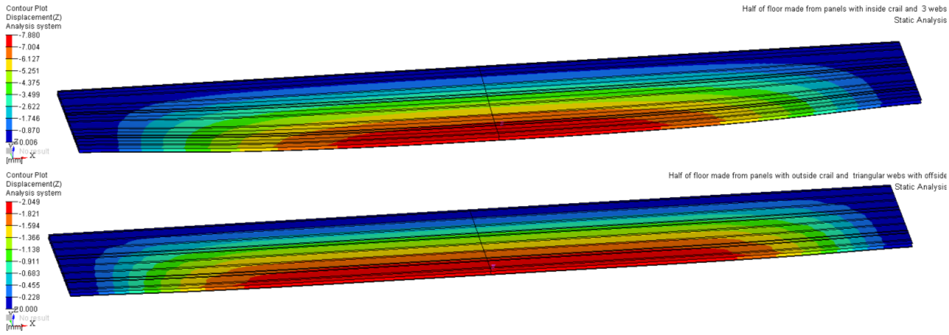

Figure 5 Half of floor made from panels: top) inside C-rail with 3 webs, bottom) triangular web with offset

Summarized in Table 1 are the most important results which determine the technical parameters of the floors made from different type of panels.

Table 1 Summary of most important technical parameters

Panel type	Stress (ZZ) in C-rail and Bolt [MPa]	C-rail Displacement [mm]	Floor Deflection [mm]	Max. weight applied on C-rail (4 bolts) under 3g [kg]	Mass of one floor panel [kg]
Squared profile	263,37 -333,73	0 -1,81	2.20	175	89,18
Triangular profile	116,26 -356,38	0,16 -0,20	2.04	175	113,26
Triangular profile with offset	109,72 -355,78	0,18 -0,23	2.05	175	106,87
Inside C-rail with 3 webs	119,64 -306,02	0,02 -0,17	7.88	65	105,55
Inside C-rail with 2 webs	115,05 -306,51	0,03 -0,24	7.99	65	101,32

3.4 Additional inputs for commonality decision

Technical inputs are critical when selecting the best solution, but the final cost is also highly weighted. Cost information was difficult to obtain since it is very due to the sensitive nature of competitive data. Generally the cost of aluminium extruded panels is determined by raw material cost, extrusion cost, and the necessity of further processing (machining, welding). The least expensive solution turned out to be the squared profile, and the most expensive was the triangular profile. The optimised solution was approximately 10 present cheaper than the widely used triangular solution. Another factor, which highly influences panel selection, is industrialization. In this study, the most influential elements included lead time, the number of parts eliminated, customization feasibility, failure inspection and rework rates, how often the solution is currently utilized, and material waste.

Many times it happens that in different vehicles there is different equipment and thus different panel designs. Such a situation results in long development and manufacturing time for panels. This scenario will be avoided by introducing common panels. This solution could in theory decrease development time to 37 weeks from 120 needed for different panels currently used (extrusion + welding) and manufacturing would be faster because of usage of the same tooling.

The possibility of customization is also an important factor in determining which panel is the preferred commonality option. Customization represents the possibility of adding other equipment in a different location than C-rail. In cases when other equipment added, a squared profile may not withstand the new load. This can be caused not only by heavier equipment but also by the more critical load location between two webs. In the case of triangulation, the location of new added C-rails will possibly also decrease the panel strength, but in a smaller magnitude.

When a particular panel has already been in use, there is a potential return of experience about it in all lifecycle steps. This means it will be easier to do all the steps again even with small modifications. In the case of a new profile, even if it is theoretically better, there is a risk that in one of the project steps unexpected problems will be found. Different types of insulation are frequently applied on floor and roof panels. In company products, the thickness of insulation is similar to the height of the outside C-rail which allows ease of assembly, assures lack of interference, and requires no additional modifications in insulation. In the case of an inside C-rail, there may need to be an adjustment of the insulation, and there is the possibility of interference with assembly components.

4. DISCUSSION

Based on the analysis of displacement and stress concentration, it can be concluded that squared profile is the least preferable solution. The triangular profile also has a stress concentration in the area of the joint between the web and flange, but its magnitude is relatively low. Gap opening analysis shows that panels with an inside C-rail can potentially have problems with loosening of the interface. For floor creation, “Triangular profile with offset” is the preferred option for equipment which weighs between 65 and 175kg (divided among 4 screws), mostly due to a good weight to performance ratio. Under this load condition, squared profile has high stresses and C-rail displacement. The original triangular profile is too heavy, and it has stress concentration in more critical areas than the triangular panel with offside. Panels with an inside C-rails are not allowed to be used under heavy load because of tightness problems. That is why in above table, the maximum weight applied on the C-rail is only 65kg. In addition, even for lighter equipment, this solution is prohibited to be used in an underframe because of the large floor deflection. For smaller weight equipment (less than 65kg mounted on four bolts), inside C-rail or squared profile could be an option on the roof. An inside C-rail with 3 webs has the additional benefit that the top flange is less deformed under the load than in other solutions, which in some cases could be beneficial. Depending on the actual location of the implementation of the panel, additional constraints and restrictions of different panels will determine the preferable option.

Taking into considerations all the technical inputs, additional inside company inputs as well as general market trends it was decided to make the triangular panel with offset common across different products. Since the exact requirements are only known for the rail vehicle and not for buses further work is necessary, but general design concept, and manufacturing type may be common. Lightweight design was preferable option, but as well it need to withstand loads coming from potential equipment such as batteries or other heavy components.

5. CONCLUSIONS

Finite element analysis turned out to be a suitable method of initial selection of commonality opportunities in which strength to weight ratio is critical. Based on the analysis, panels with an inside C-rail, although having many theoretical benefits, was ruled out as an under frame component. It is still possible to use it, as a roof component since equipment there in many cases is lighter and interface failure is less critical. Best technical performances, as well as additional external and internal benefits, were achieved with the triangular panel with offset. This panel was created during the study as a variation of the most frequently used triangular solution. The newly developed panel weighs less than the original that is used by a variety of manufacturers. Moreover, results show that stresses are smaller and in less critical locations than in the original design. This article provides proof that finite element analysis is a good initial step for commonality affords, which at the same time can lead to optimization of existing components. Moreover it presents an opportunity for companies producing railway and road vehicles to look for other commonality opportunities. Currently, there is a small number of shared components, but if future work will focus on part reuse it is possible to achieve higher commonality level. This approach can potentially save resources and improve efforts for developing new concepts or modifications are made. As well as improve manufacturing, purchasing and decrease price of parts. All of those benefits together may allow companies to introduce lightweight products at reasonable cost for end used causing a wide spread of new environmentally friendly solutions.

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