Structural and kinematic aspects of some bar mechanisms for deployable structures

IOP Conf. Series: Materials Science and Engineering **591** (2019) 012077 doi:10.1088/1757-899X/591/1/012077

Structural and kinematic aspects of some bar mechanisms for deployable structures

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Abstract. Transformable structures in architecture can change their shape or function in response to varying climatic conditions, changing environment and needs for different functional requirements or to emergency situations. Depending on how the transformation is doing, transformable structures can be deployable or demountable, as a kit-parts system. Deployable structures can also be divided in four main groups: spatial bar structures; foldable plate structures; tensegrity structures; and membrane structures. In this paper, some planar bar mechanisms proposed by Ten Fold Engineering company, which can be integrated in deployable structures, will be discussed.

1. Introduction

Transformable architectural structures can change their shape or function in order to dynamic answering to modern problems, such as: responsiveness to climatic influences, creating temporary spaces, or change of use, [1, 2]. Based on the transformation solution, there are two main groups of transformable structures: the structure transformation is done by some mechanisms, which enable the structure to deploy from a compact configuration to an expanded one that can fulfil its architectural function, or by designing the structure as a demontable kit-of-parts system, [2]. In our paper we will focus our attention on structures from the first category, which are also called deployable structures.

Deployable structures can also be classified in four main groups: structures based on spatial bar mechanisms consisting of articulated bars; foldable plate structures consisting of articulated plates; tensegrity structures; and membrane structures. Because of their wide applicability in the field of mobile architecture, their high degree of deployability and a reliable deployment, two sub-categories are studied in greater detail: bar structures, generally, and pantograph (scissor-like) structures, especially, and foldable plate structures, respectively [3-6].

Scissor based structures are lattice expandable structures consisting of articulated bars. Although many architectural applications have been proposed till now for these mechanisms, few of them have been constructed at full-scale due to the mechanical complexity of their systems during the folding and deployment process, [7].

A special case is represented by Ten Fold Engineering company (in UK), which has developed a series of modular, self-deploying structures that can be instantly unfolded without the need for builders, cranes or foundations. The initiative of this company innovates by creating and designing various relocatable buildings and structures based on a family of rigid bar mechanisms. As they have been demonstrated by their simulations or real structures, various combinations of space and facilities can be obtained. Different designs have already been imagined in order to meet the needs and desires

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of the customers, [8, 9]. Besides a regular mobile home, the Ten Fold mechanisms can offer mobile hotels, bridges, huts, solar panels, lorries, antennas, stairways, larger halls or road barriers, and so on, [5]. Mobile shelters for film crews, festivals, sports events or leisure could also definitely be additional uses.

In this paper, some planar bar mechanisms proposed by Ten Fold Engineering company, which can be integrated in deployable structures, will be discussed.

2. Bar mechanisms for deployable structures

The main goal of the research on bar mechanisms based structures is to find solutions of mechanism that can allow the structure to be folded into a compact bundle but also to get a maximum expanded configuration, with high rigidity, too. To do that, the first way is to find optimum structure of the mechanism, which must need a minimum number of actuators to unfold/fold it, and, then, the next step is to solve the dimensional synthesis problem.

A first planar mechanism (figures 1) discussed here was proposed by Ten Fold Engineering in building different deployable structures. It is an eight bar mechanism that can have a very compact folded configuration (figure 1(a)) and, also, may be locked in a deployed configuration (see figure 1(c)).

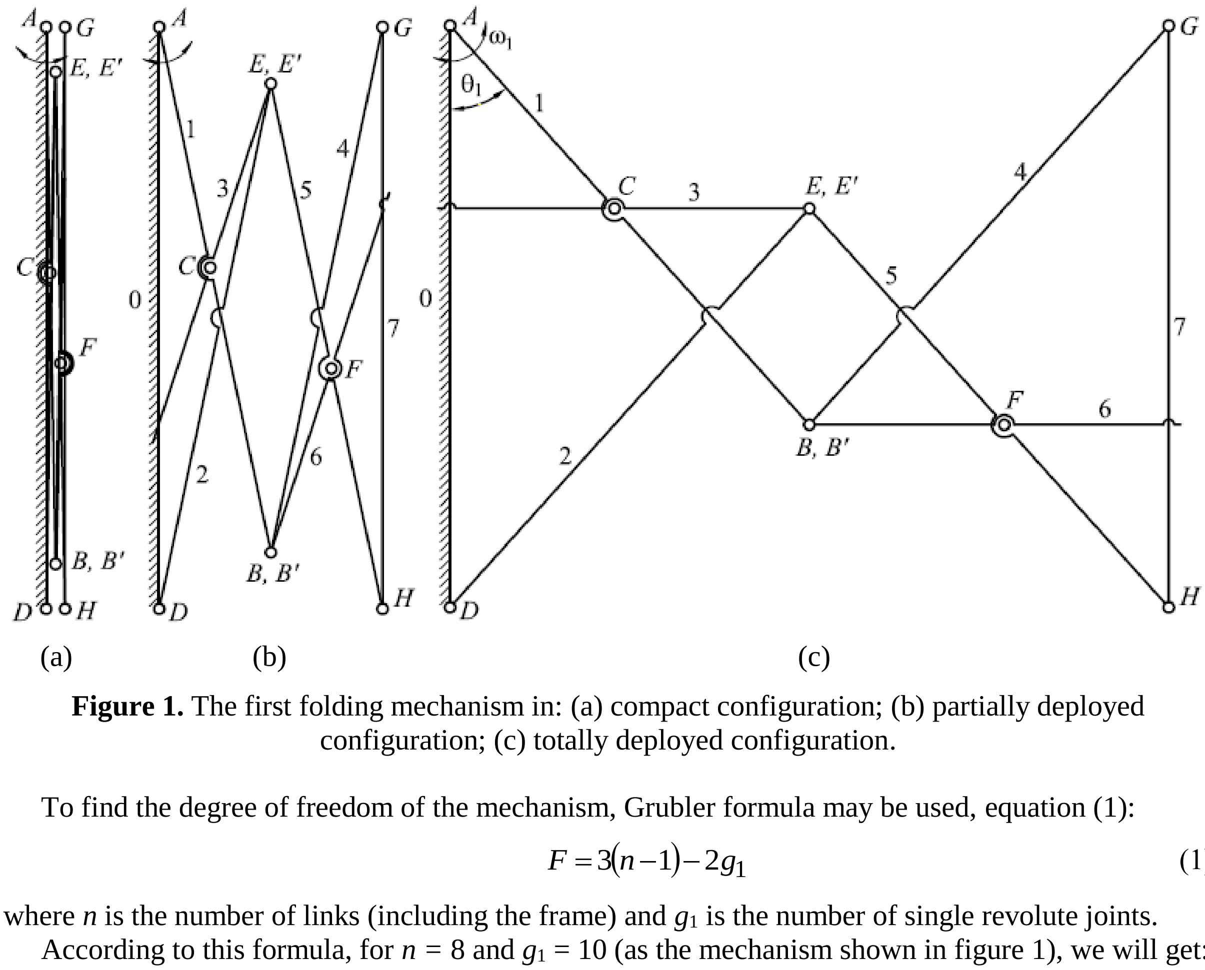

Figure 1. The first folding mechanism in: (a) compact configuration; (b) partially deployed configuration; (c) totally deployed configuration.

To find the degree of freedom of the mechanism, Grubler formula may be used, equation (1):

$$F = 3(n-1) - 2g_1 \tag{1}$$

where n is the number of links (including the frame) and g_1 is the number of single revolute joints.

According to this formula, for n = 8 and g_1 = 10 (as the mechanism shown in figure 1), we will get:

$$F = 3(8-1) - 2 \cdot 10 = 1 \tag{2}$$

It means that a single actuator is needed to actuate the mechanism. This actuator is suitable to be placed to A joint (the link 1 will be the driver link).

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If we consider θ_1 the rotational angle of the driver link, the area A_1 of a wall formed by this mechanism in the deployed configuration will be equation (3):

$$A_1 = 2l_{AB}^2 \sin\theta_1 \tag{3}$$

considering that $l_{AB} = l_{AD}$.

Another view of the mechanism with overlapped compact, partially deployed and totally deployed configurations is presented in figure 2.

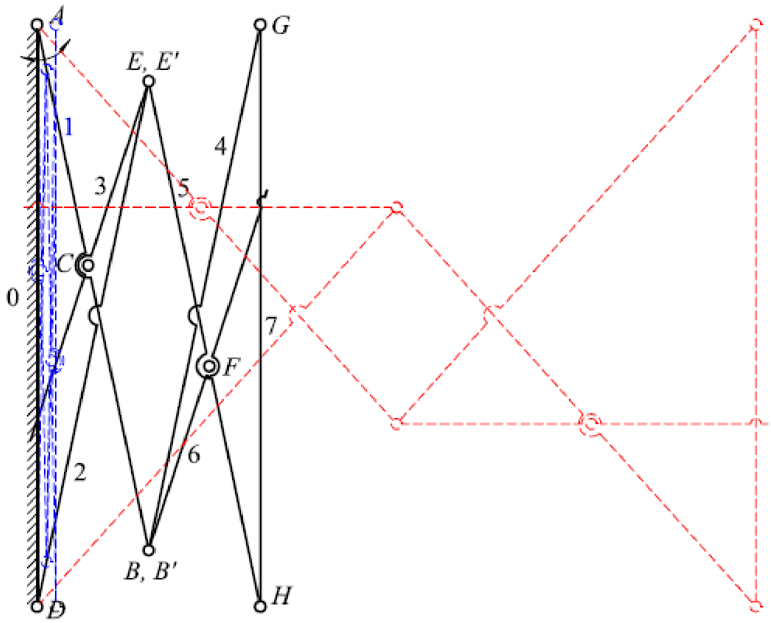
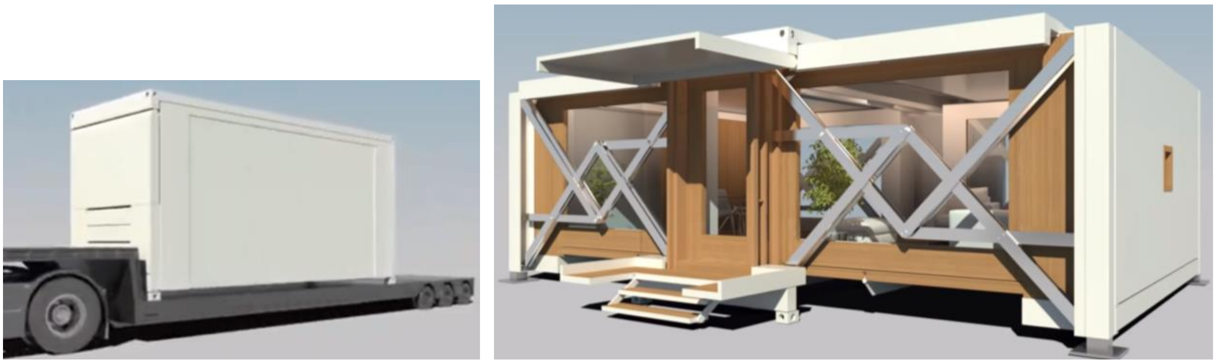


Figure 2. The first folding mechanism with overlapped compact, partially deployed and totally deployed configurations.

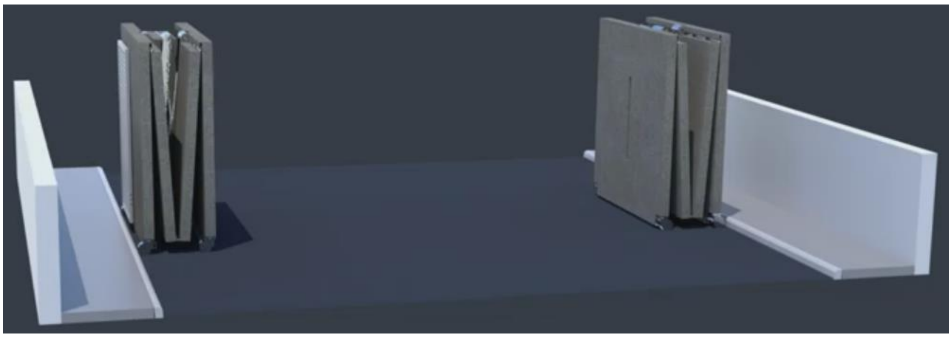
Two examples of deployable structures that may use this mechanism will be given here. The first example is a mobile house (see figure 3).



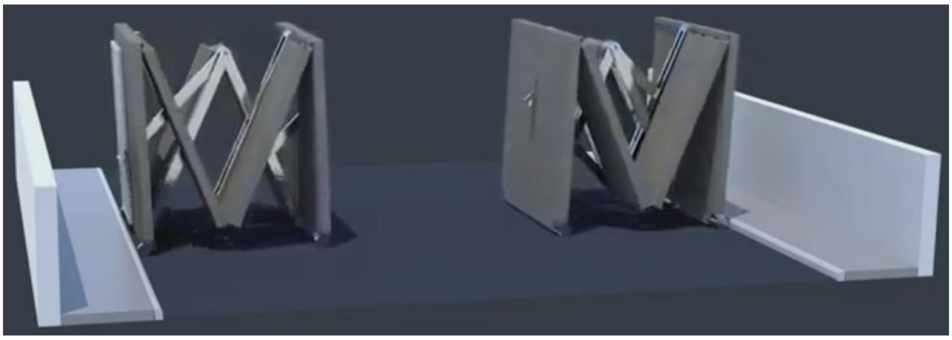
(a) (b)

Figure 3. Mobile house in: (a) compact configuration (on a trailer); (b) deployed configuration [9].

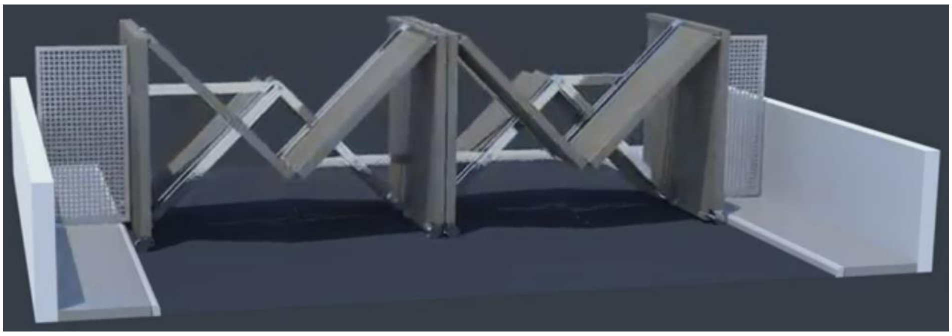
Another application of the mechanism described here road barrier, represented in folded, partially deployed and totally deployed configurations (figure 4).



(a)



(b)



(c)

Figure 4. Road barrier in: (a) compact configuration; (b) partially deployed configuration; (c) totally deployed configuration, [9].

The first simulations have been done, considering the coordinates of the mechanism nodes in the fully extended configuration as illustrated in figure 5. We have to note that no dimensional synthesis of this mechanism has been realized till now. As consequence, the mechanism could not fold in the optimum compact configuration. The driving link 1 could only rotate with an angle $\theta_1 = 32$ degree (see figure 6), starting from the extended configuration. It means that the simulated mechanism could only fold till the partially deployed configuration represented in figure 1(b). Also, the trajectory of the *G* and *H* nodes are not yet straight lines, as they should be, but as they are presented in figure 7, even if the link 7 has not a significant rotation around *z* axes, as seen in figure 8. The paths of the *A*, *G* and *H* nodes are shown in figure 9.

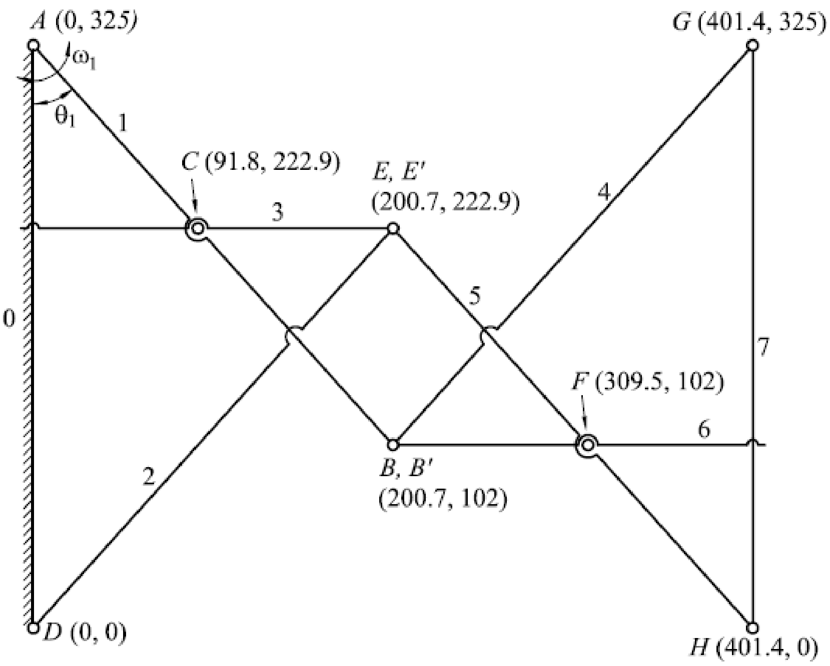


Figure 5. Nodes coordinates of the simulated mechanism, in totally deployed configuration.

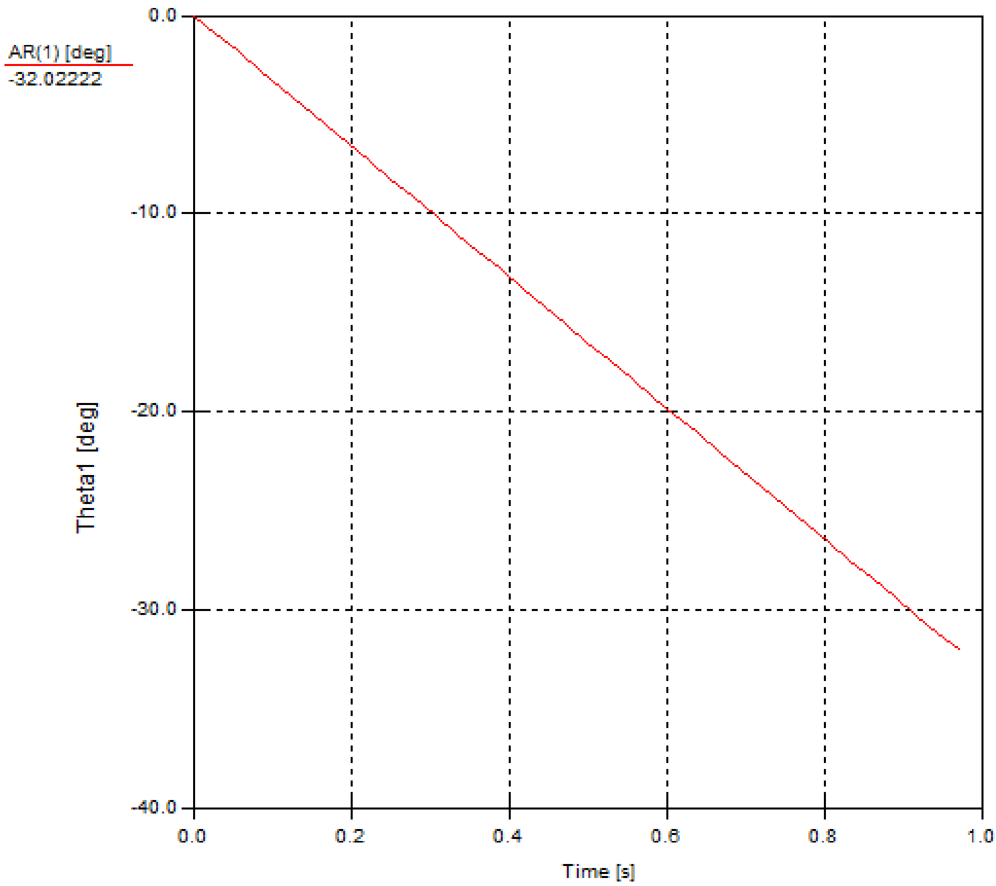
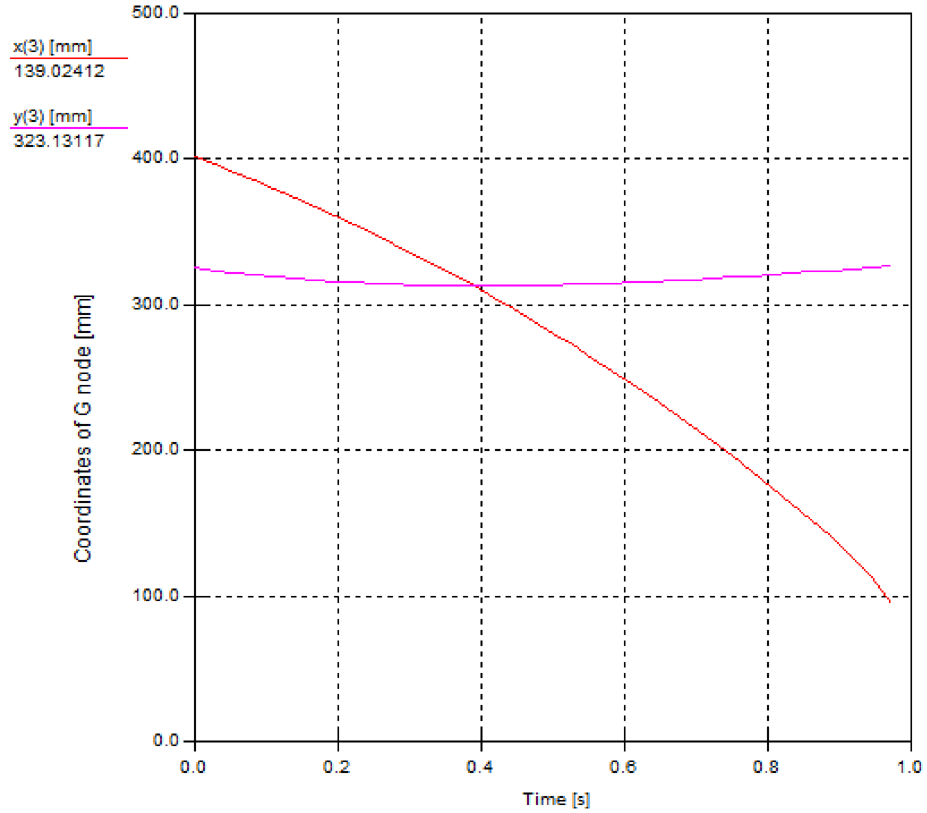
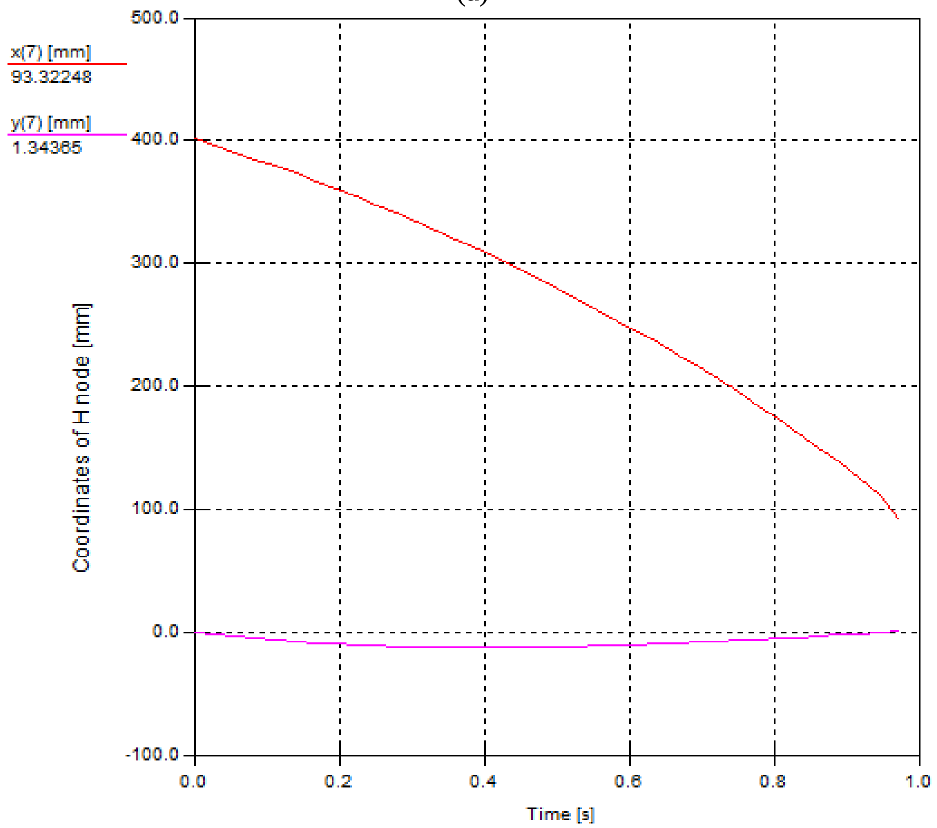


Figure 6. Relative angle θ_1, starting from totally deployed configuration to the partially deployed one.



(a)



(b)

Figure 7. Coordinates of the nodes during folding: (a) for *G* node; (b) for *H* node.

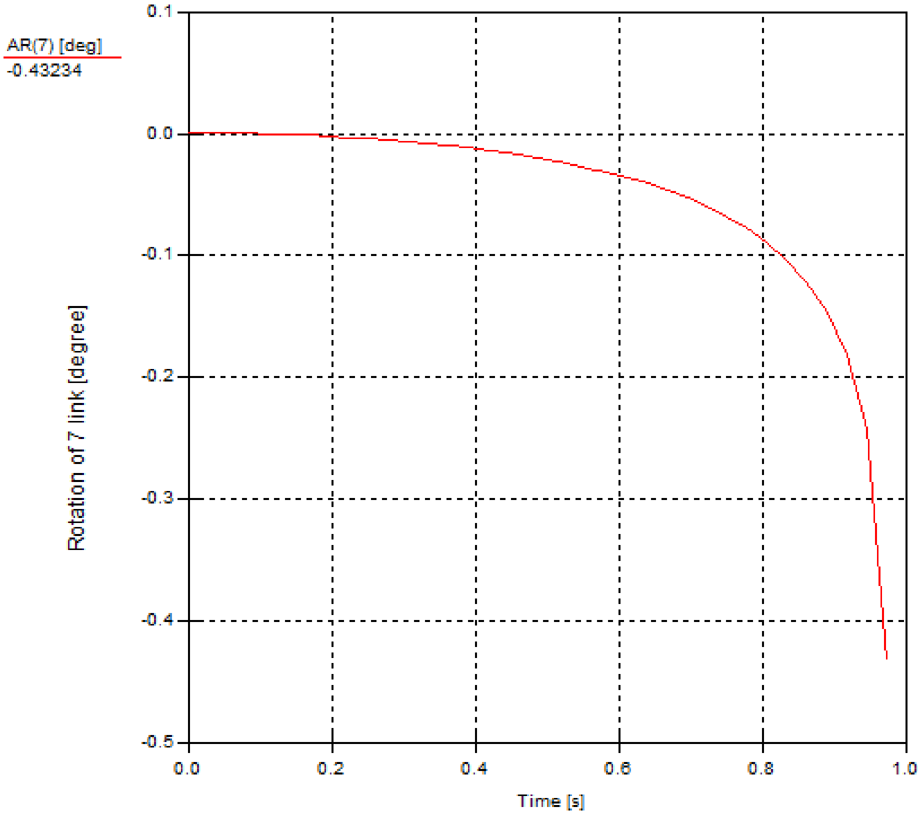


Figure 8. Rotation angle of the 7 link around *z* axes, during folding.

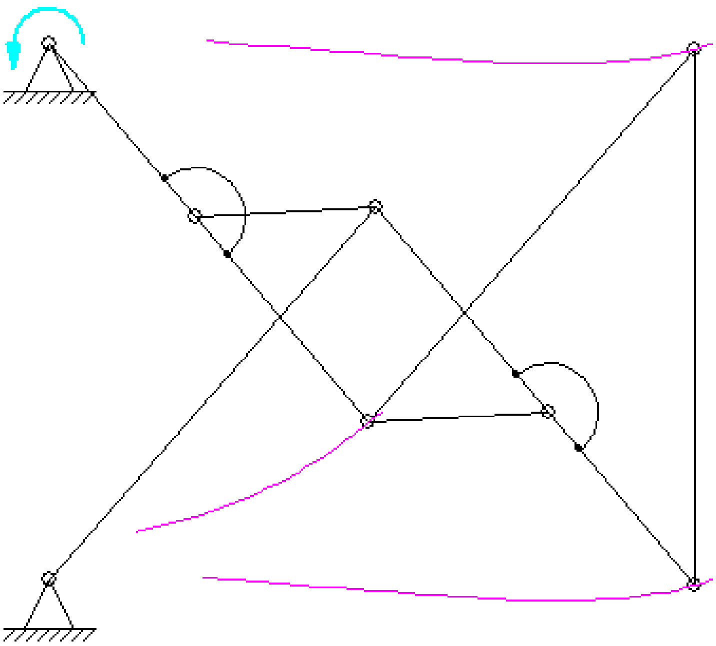


Figure 9. The paths of *B*, *G* and *H* nodes, during folding.

The second mechanism discussed here is shown in figure 5. It has the total number of links, $n = 8$ and the number of rotary joints, $g_1 = 13$. As we may see in the example of its application, this mechanism may allow to built deployable structures (mobile house, for example) with shading system (see figure 10).

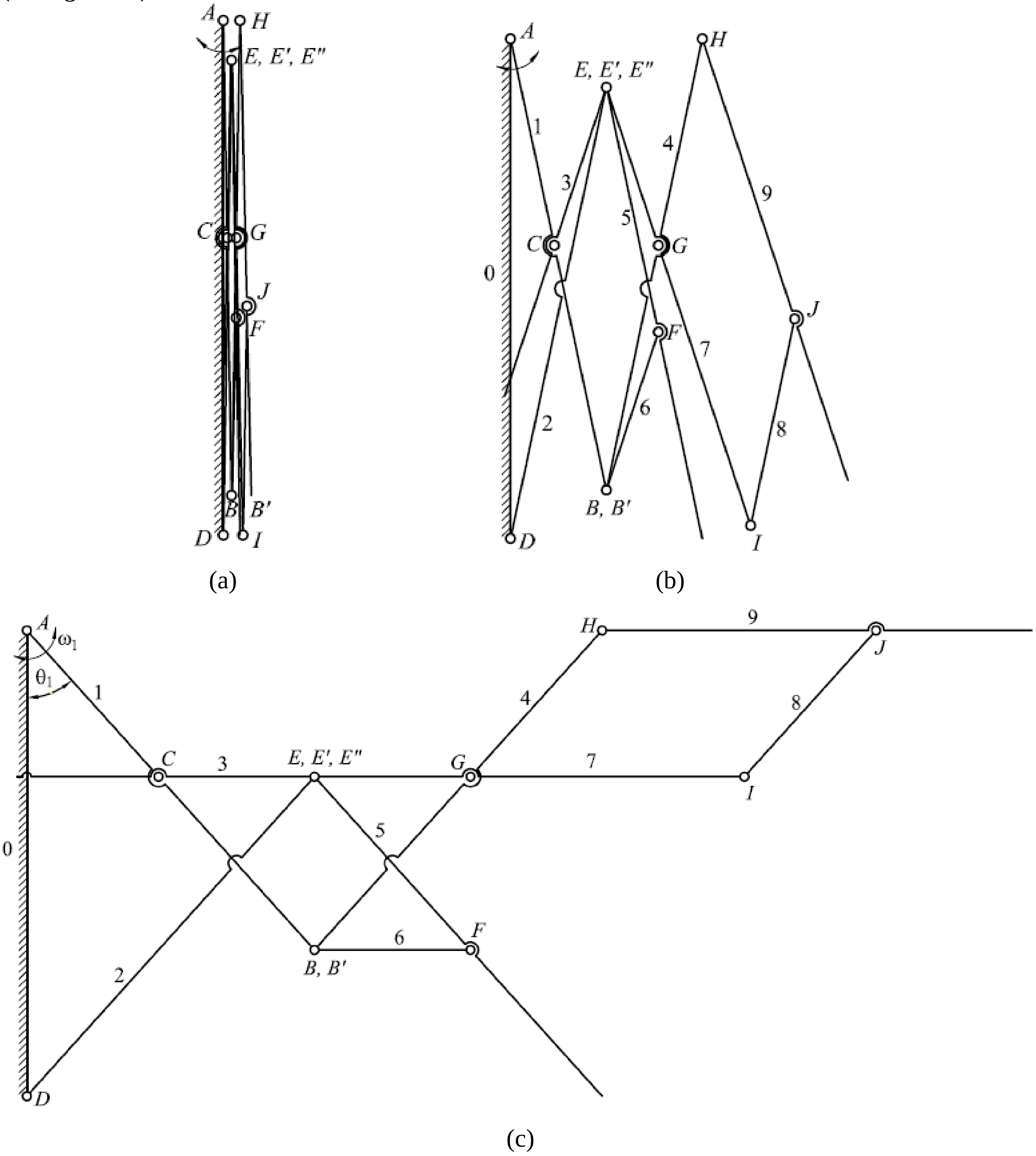


Figure 10. The second folding mechanism in: (a) compact configuration; (b) partially deployed configuration; (c) totally deployed configuration.

According to Grubler formula, for n = 10 and g_1 = 13, the number of degrees of freedom of this mechanism is:

$$F = 3(10-1) - 2 \cdot 13 = 1 . \tag{4}$$

Again, a single actuator is needed (placed to A joint) to actuate the mechanism, which has as advantage a minimum number of actuators for the entire spatial structure, a smaller cost, a simpler control algorithm, and so on. If θ_1 is the rotational angle of the driver link, the area A of the surface covered by a wall based on this mechanism, in the deployed configuration, will be, equation (5):

$$A_2 = (2l_{AB}\sin\theta_1 + l_{HJ})l_{AB}, \tag{5}$$

considering that $l_{AB} = l_{AD}$.

An overlapped view, for compact, partially deployed and totally deployed configurations of the mechanism, is presented in figure 11.

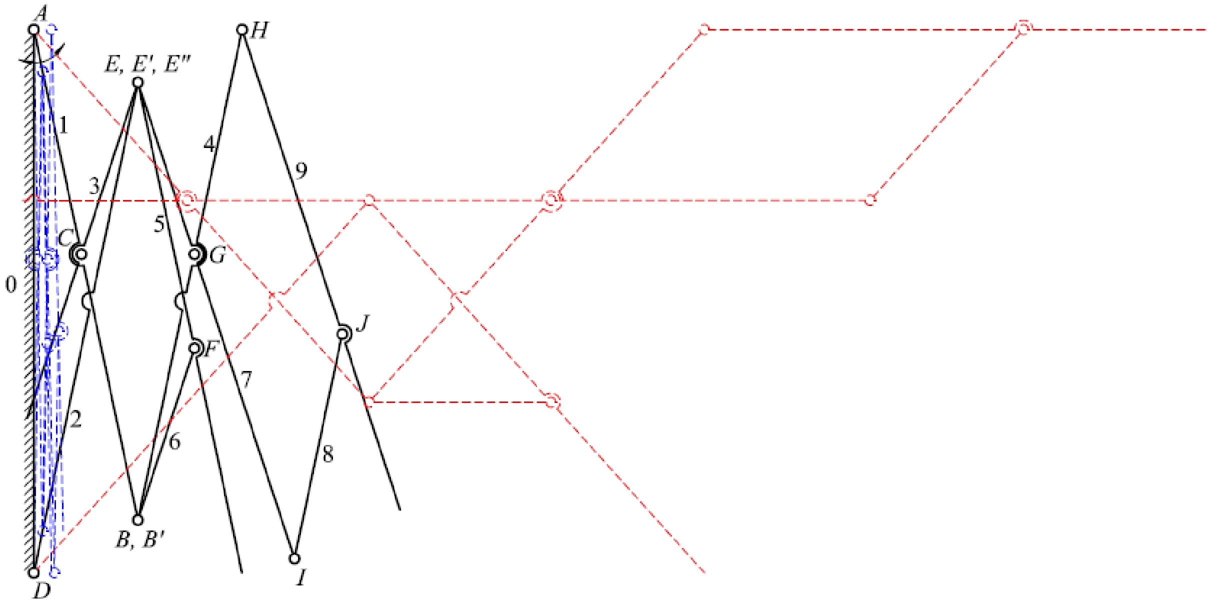


Figure 11. The second folding mechanism with overlapped compact, partially deployed and totally deployed configurations.

An application of the second mechanism in building a mobile hose is shown in figure 12, [9].

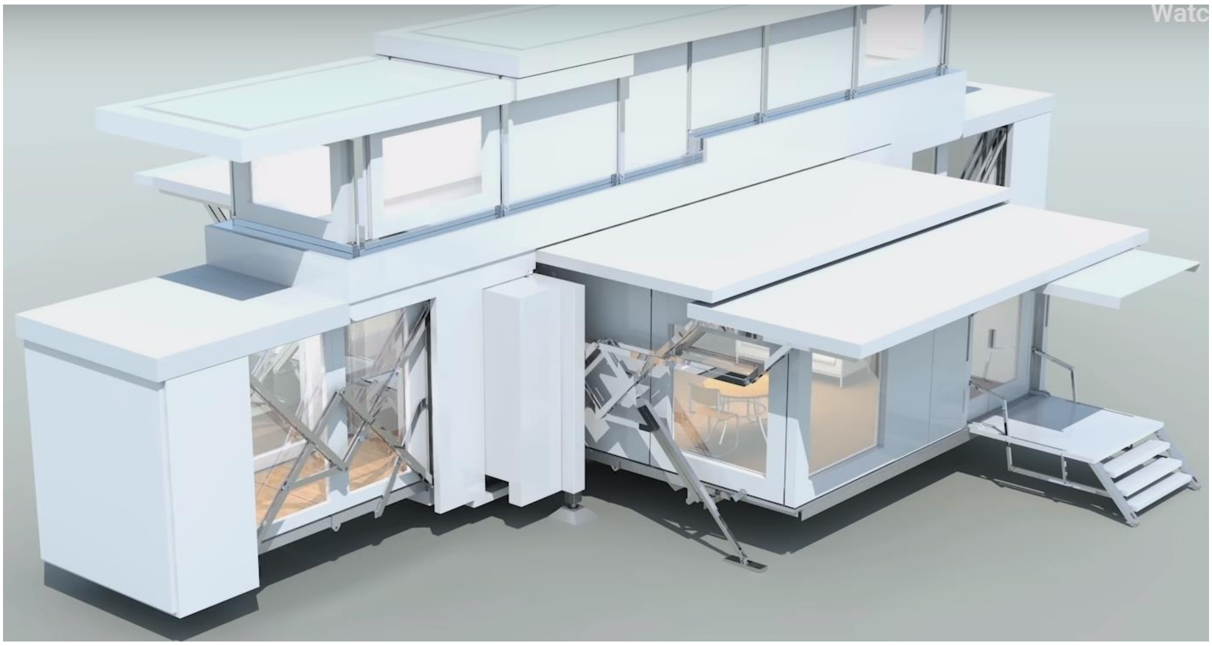


Figure 12. Mobile house [9].

3. Conclusions

Transformable structures in architecture can change their shape or function in response to varying climatic conditions, changing environment and needs for different functional requirements or to emergency situations. Depending on how the transformation is doing, transformable structures can be deployable or demountable, as a kit-parts system. According to their structural system, deployable structures can also be divided in four main groups: spatial bar structures; foldable plate structures; tensegrity structures; and membrane structures. In this paper, some planar bar mechanisms proposed by Ten Fold Engineering company, which can be integrated in deployable structures, have been discussed. First, a structural analysis of these mechanisms has been performed and then, some simulations of the first mechanism discussed here have been done. Also, some applications proposed by Ten Fold Engineering company have been presented. As we see in the results of these simulations, the mechanism cannot fold into the compact configuration due to the fact that not an optimization of the links dimension was performed till now. The dimensional synthesis of these mechanisms will be the subject of near future research.

4. References

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