P2-07

ROBOTIZED DEPLOYMENT OF *TRUSS-Z* MODULAR BRIDGE

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INTRODUCTION

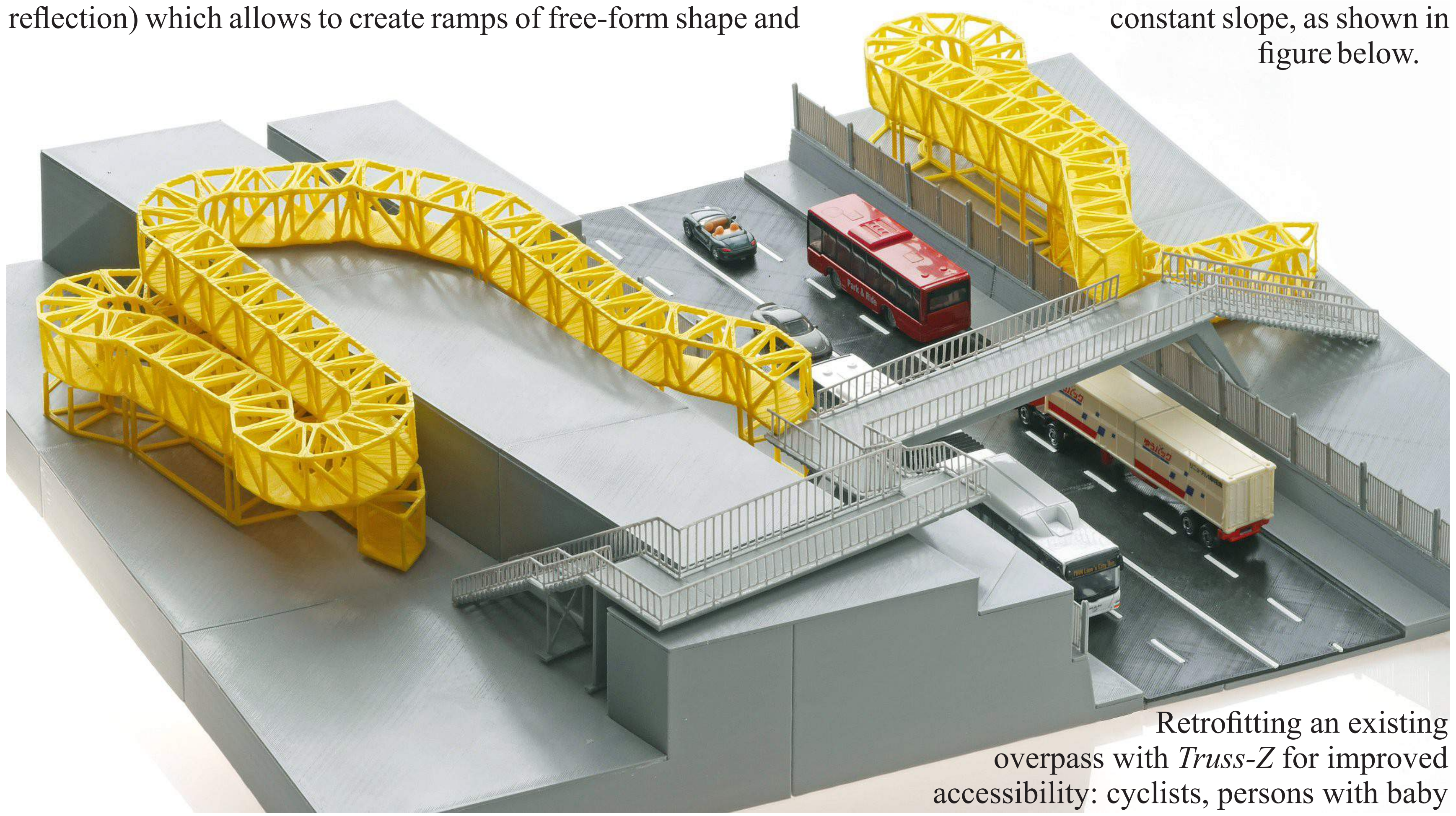
Extremely Modular Systems (EMS for short) is a family of geometrical concepts introduced in [1], where a single module allows for creation of free-form shapes and structures. There are four fundamental advantages of EMSs:

- Economical - as they are suitable for mass fabrication, thus lowering the cost so they can be broadly applied;
- Functional - as they allow for reconfiguration, expansion, reduction, rapid deployment;
- Robustness - since every module which failed can be easily replaced with an identical but functional one;
- Scientific - as they are suitable for intelligent mathematical modeling.

EMS, however, has one major disadvantage - unintuitiveness, i.e. its manual assembly is usually infeasible. The number of all module combinations of given type „explodes" soon with their growing number. Thus, for realistic examples the selection of the best among all solutions is impossible without the use of computational methods.

TRUSS-Z FOR PEDESTRIAN RAMPS

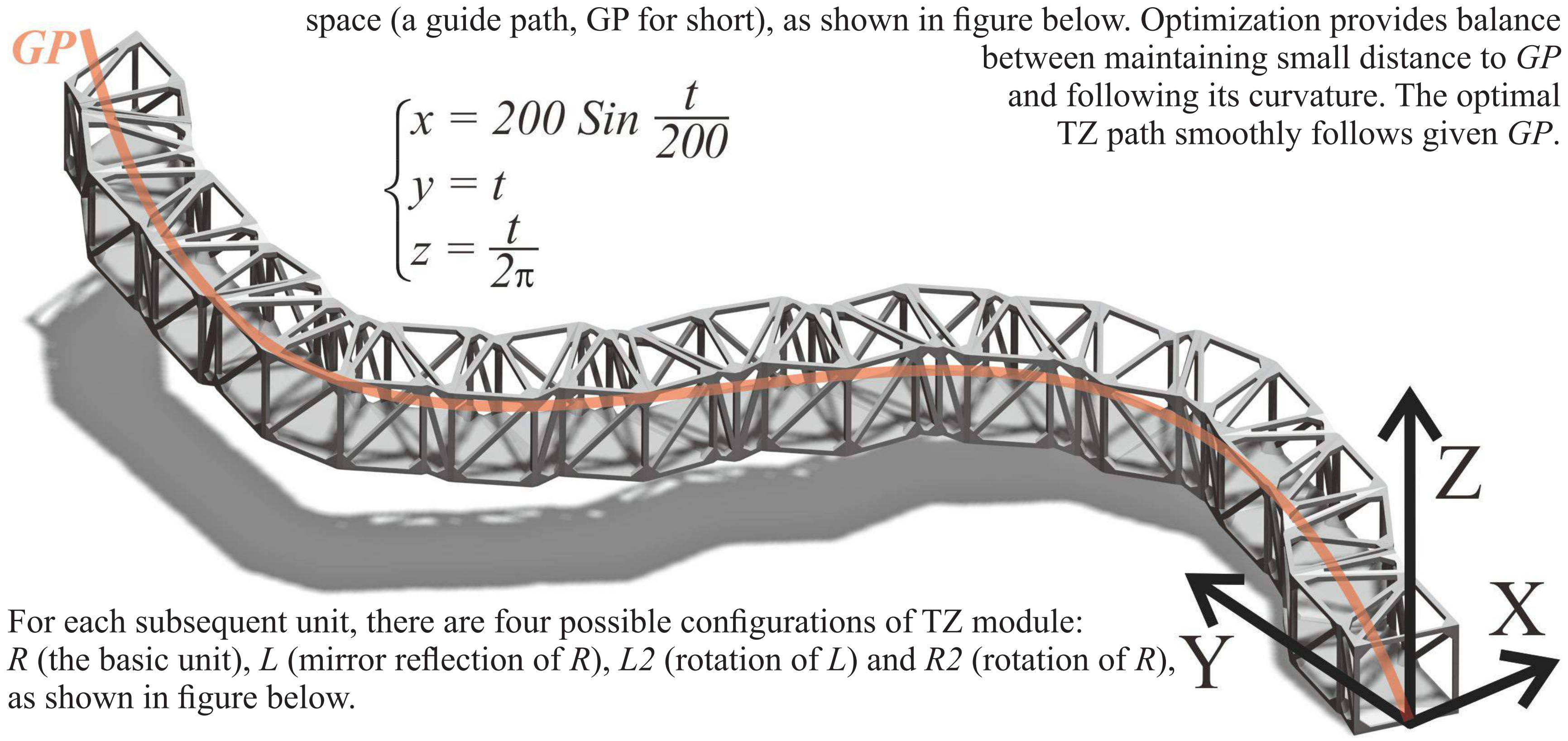
Truss-Z was the first EMS. It is a modular system [2] comprised of one truss-frame hybrid unit (and its mirror reflection) which allows to create ramps of free-form shape and constant slope, as shown in figure below.



Retrofitting an existing overpass with *Truss-Z* for improved accessibility: cyclists, persons with baby strollers, on wheelchairs can safely cross this street.

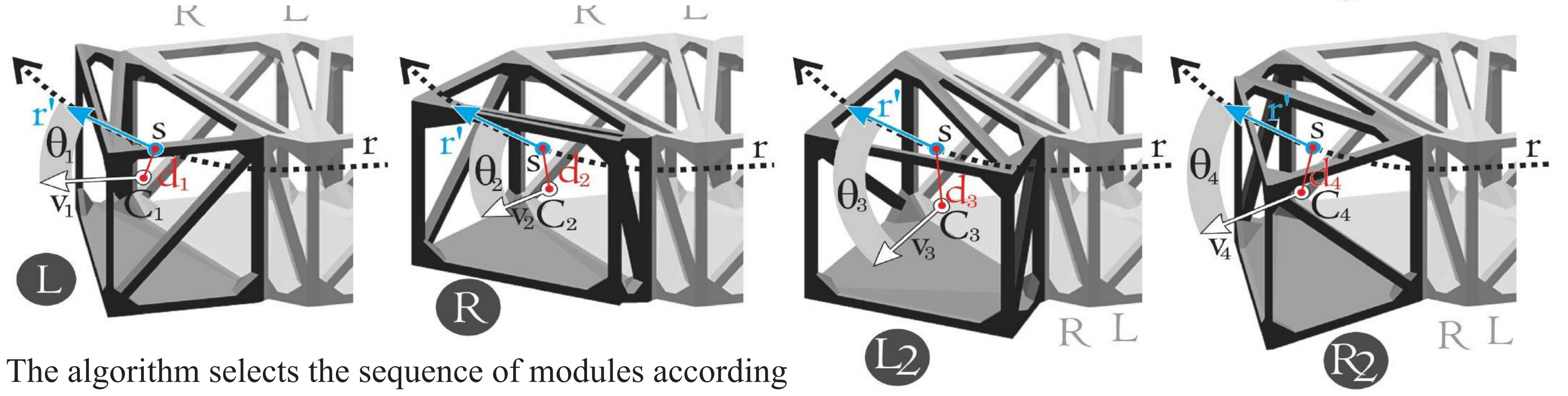
OPTIMIZATION METHODS

The simplest approach for creating a single-branch TZ path is by aligning the modules along given curve in space (a guide path, GP for short), as shown in figure below. Optimization provides balance between maintaining small distance to *GP* and following its curvature. The optimal TZ path smoothly follows given *GP*.



$$\begin{cases} x = 200\ Sin\ \dfrac{t}{200} \\ y = t \\ z = \dfrac{t}{2\pi} \end{cases}$$

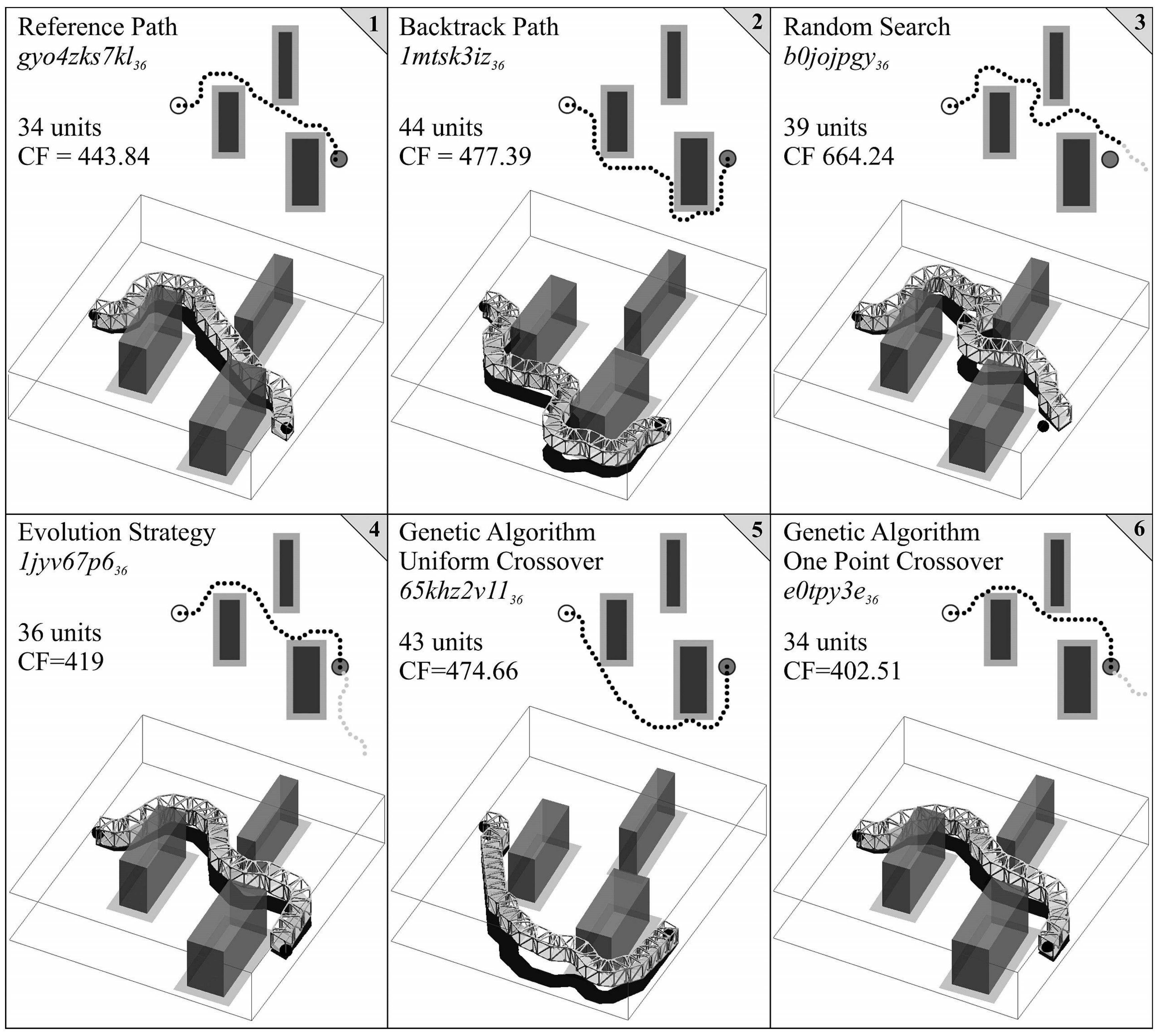
For each subsequent unit, there are four possible configurations of TZ module: *R* (the basic unit), *L* (mirror reflection of *R*), *L2* (rotation of *L*) and *R2* (rotation of *R*), as shown in figure below.

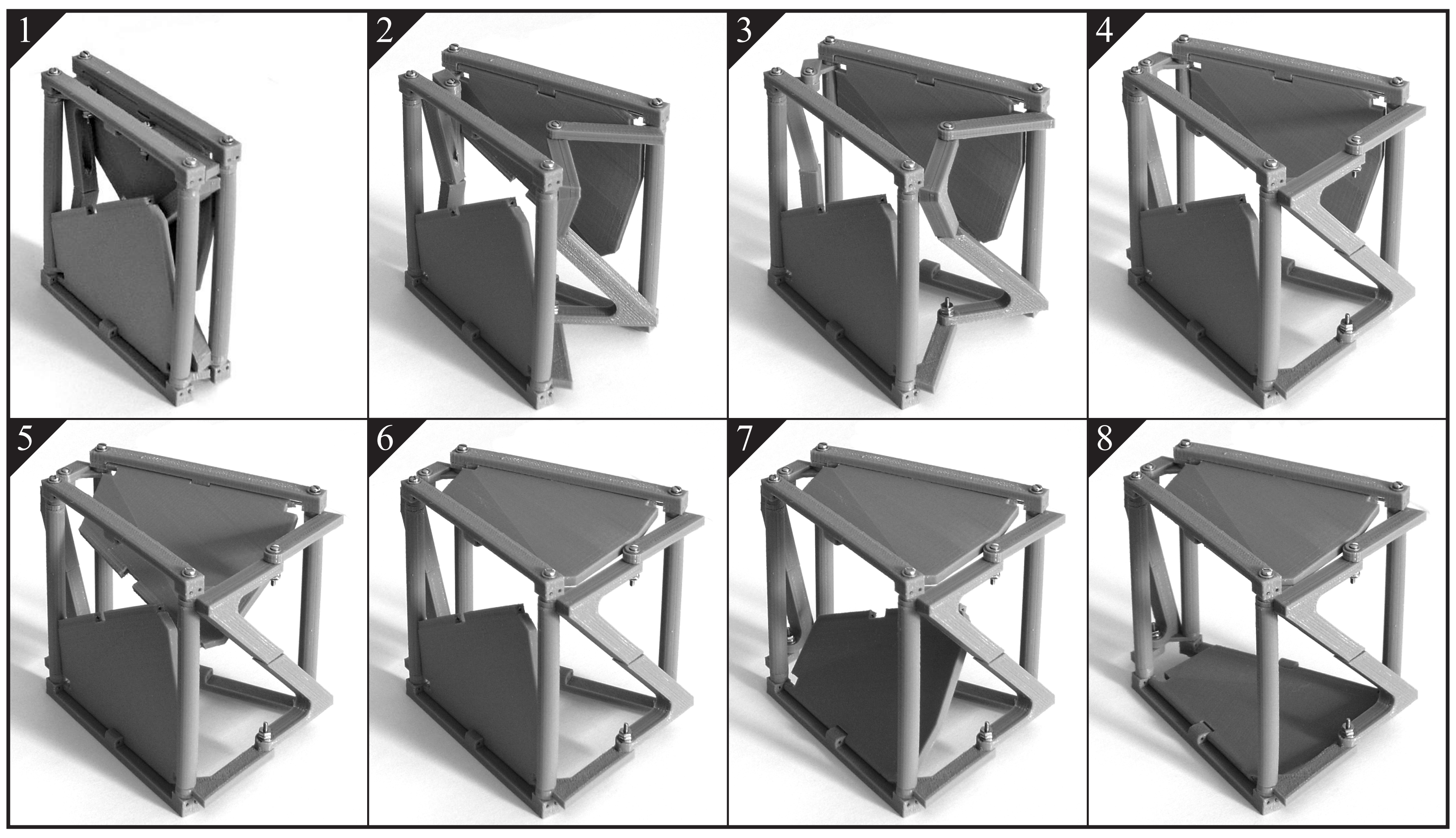


The algorithm selects the sequence of modules according to the following function:

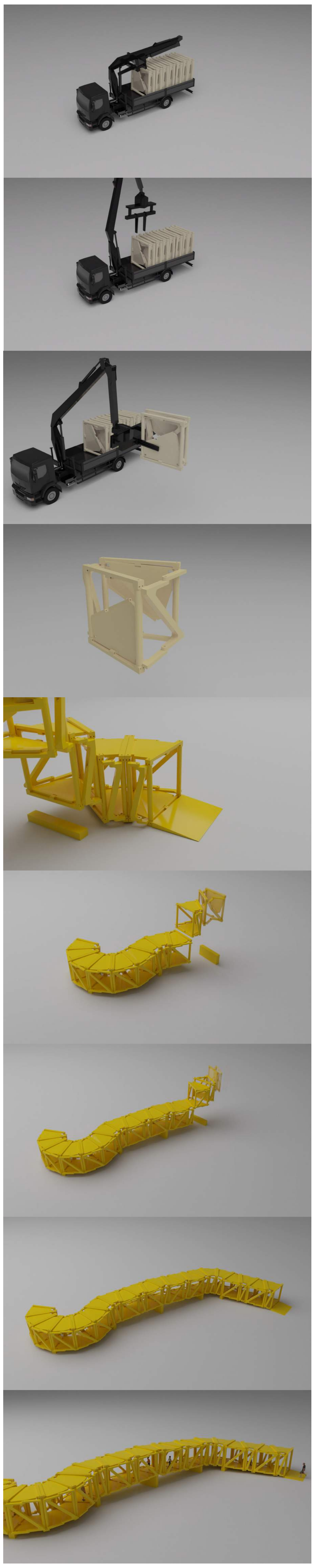
$$Minimize\,(a/b\, d_i + (1-a)(1 - v_i \cdot r'|s|))$$

where, d_i is the smallest distance between the centroid C_i of an i^{th} module and the point s on the curve r (*GP*), v_i is the vector of an i^{th} module, $r'[s]$ is the direction of r (*GP*) at point s; a and b are parameters. a is the weight (from 0 to 1) which balances the influence of angle θ_i expressed as a normalized dot product of the direction $r'[s]$ of the curve r and the vector v_i of the i^{th} module with the distance d_i between the centroid C_i of the i^{th} module and r. Since the objective function depends both on distance d_i and angle θ_i which cannot be normalized, b adjusts the ratio between them. If the *GP* is unknown, the *Truss-Z* path can be constructed by several discrete methods: manually, randomly, by backtracking or evolutionary algorithms [3], as shown in figure below.





Unfolding: 1 Stowed state. 2-4: unfolding of the sides; 5-6: deployment of top. 7 and 8: deployment of the bottom.



Optimization of multi-branch *Truss-Z* by Evolution Strategy, where the network distance was minimized has been presented in [4]. The most obvious constraint in the process of TZ path design is the location of the points to be linked by the structure. Further natural constraints are the prohibition of: self-collisions and collisions with the obstacles, such as buildings etc. Other practical constraints [5] might be: maximum allowable span of an unsupported TZ assembly, minimization of earthworks, preservation or minimal removal of the existing trees. Effective graph-theoretic exhaustive search approach for finding ideal solutions has been presented in [5]. Image processing methods parallelized with GPU have been implemented for effective TZ layout optimization in [6].

STRUCTURAL OPTIMIZATION

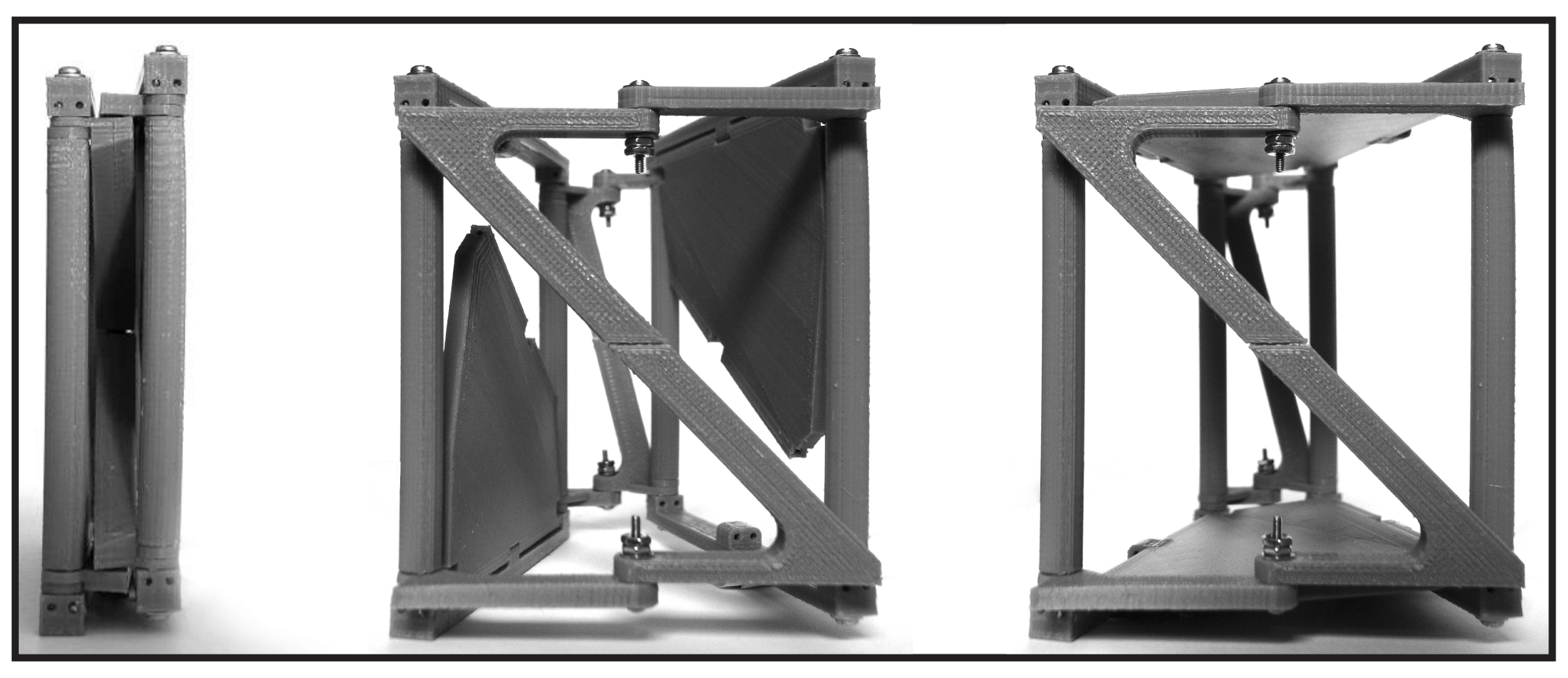
The first attempt for structural optimization of TZ module, where the problem of sizing optimization of TZM members was considered for an arbitrarily assumed particular outer geometry of the module was presented in [7]. In later paper [8], the authors aimed to balance between two different types of objectives: 1. The ability of the module to generate a variety of free-form shaped global TZ structures. This is quantified by assessing the directionality of the exit modules and the spatial distribution of their end points, which are required to be possibly uniform. The aim is to promote systems that are flexible enough to comply with intricate geometrical constraints of real construction sites. 2. The structural quality of the generated global TZ structures. It can be expressed in analogy to a structural optimization problem, in which mass is minimized subject to constraints that prevent yielding and buckling.

DEPLOYABLE *TRUSS-Z*

The concept of foldable Truss-Z module, has been presented in [9]. It substantially reduces the module size for transportation or storage. The volume reduction ratio (*VRR*) compares the bounding volumes of the module in stowed (VB_s) and deployed (VB_d) states. *VRR* for foldable *Truss-Z* is calculated as follows:

$$VRR = VB_s / VB_d = 4.212\ \mathrm{m}^3 / 12.171\ \mathrm{m}^3 = 0.35$$

Figure below shows the top view of the foldable *Truss-Z* module, and illustrates in three stages the compactness of the stowed stage.



The sequence of figures on the right (from top to the bottom) illustrates the concept of automated deployment of Truss-Z bridge: i. stowed modules are transported to the site, ii. robotized manipulator unfolds every module and iii. attaches it sequentially to the previous module. After completion of this procedure, the bridge is ready to serve the users.

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ACKNOWLEDGEMENTS

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