第I部門
骨組・骨組部材
2023年9月14日(木) 11:10 〜 12:30 I-1 (広島大 東広島キャンパス総合科学部講義棟 Ｋ１０３)

[I-12] Extremely modular Truss-Z pedestrian ramp Extremely modular Truss-Z pedestrian ramp

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キーワード：モジュラリティー、折り畳みメカニズム、離散最適化、自由フォーム、ペデストリアンランプ
Modularity, Folding mechanism, Discrete Optimization, Free-form, Pedestrian Ramp

Extremely Modular Systems (EMS for short) is a family of geometrical concepts introduced in 3), 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.

Extremely modular Truss-Z pedestrian ramp

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1. Introduction

Extremely Modular Systems (EMS for short) is a family of geometrical concepts introduced in [3], where a single module allows for creation of free-form shapes and structures. There are four fundamental advantages of EMSs:

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- 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.

2. Truss-Z for pedestrian ramps

Truss-Z (TZ for short) was the first EMS. It is a modular system ([6]) 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 Fig.1.

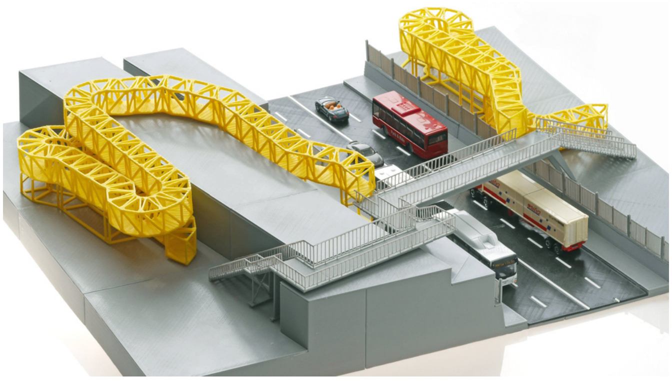

Fig. 1 Retrofitting an existing overpass with *Truss-Z* for improved accessibility: cyclists, persons with baby strollers, on wheelchairs can safely cross this street.

3. 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 Fig.2.

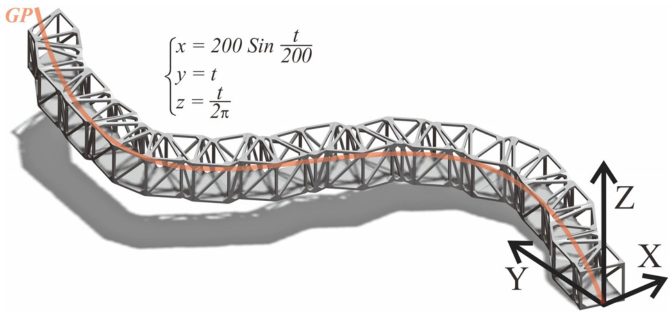

Fig. 2 Optimization provides balance between maintaining small distance to GP and following its curvature. The optimal TZ path smoothly follows given GP.

For each subsequent unit, there are four possible configurations of TZ module: R (the basic unit), L (mirror reflection of R), L_2 (rotation of L) and R_2 (rotation of R). The algorithm selects the sequence of modules according to the following function (1):

$$Minimize(\frac{a}{b}d_i + (1-a)(1 - v_i \cdot r' \,|s|)) \tag{1}$$

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 TZ path can be constructed e.g. by *backtracking*. Although the results produced by backtracking are allowable, most likely they are not globally optimal. For more information on preliminary study on TZ including multi-branching (both by GPs and backtracking), rigidity analysis, etc. see [6].

Keywords Modularity, Folding mechanism, Discrete Optimization, Free-form, Pedestrian Ramp
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Application of Evolutionary Algorithms for multi-objective TZ optimization has been presented in [7]. The cost function (CF) included: minimization of the number of TZ modules, minimization of the "reaching" error and minimization of the collisions with the environment. The results are collected in Fig.3.

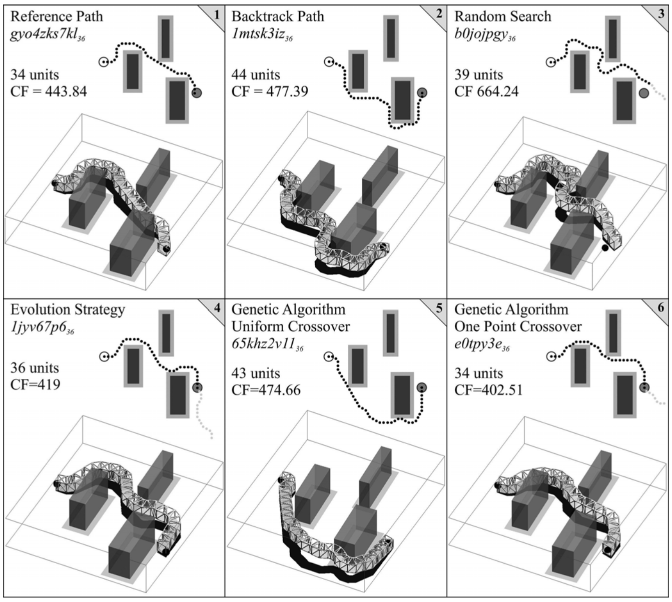

Fig. 3 Top row: TZ paths linking two points in constrained environment constructed with manual, backtracking and random search. The bottom row: TZ paths constructed with meta-heuristic methods

Optimization of multi-branch TZ by Evolution Strategy, where the network distance was minimized has been presented in [2]. 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 [4] 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 [1]. Image processing methods parallelized with GPU have been implemented for effective TZ layout optimization in [4].

4. 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 [8]. In later paper [9], 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.

5. Deployable Truss-Z

The concept of foldable TZ module, which substantially reduces its size for transportation or stowage has been presented in [5]. The volume reduction ratio (VRR) compares the bounding volumes of the module in stowed (VB_s) and deployed (VB_d) states. It is calculated as follows (2):

$$VRR = \frac{VB_s}{VB_d} = \frac{4.212m^3}{12.171m^3} \approx 0.35 \tag{2}$$

The folding mechanism of TZ module is shown in Fig.4

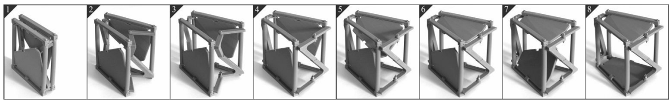

Fig. 4 Unfolding: 1 Stowed TZ. 2-4 Unfolding of the sides; 5-6 Deployment of top. 7 and 8 Deployment of bottom.

6. Conclusion

Truss-Z presents a novel approach to creation of pedestrian self-supporting ramps and ramp networks. Several modern optimization methods have been applied to this system. The authors are looking forward to the real-life applications.

Acknowledgments

This is a part of the project titled *Arm-Z: an extremely modular hyperredundant low-cost manipulator - development of control methods and efficiency analysis* funded by OPUS 17 research grant No. 2019/33/B/ST8/02791 supported by the National Science Centre, Poland.

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