In memoriam
CHRISTIAN PELECUDI, *Vicepresident of IFToMM*

PASSIVE MODULAR GROUPS WITH EIGHT ELEMENTS FROM INVERSE STRUCTURAL MODELING OF PLANAR LINKAGES

ADRIANA COMĂNESCU[1], DORU BOBLEA [2], ANTONIA ONACA[3]

Abstract. Bi-mobile mechanisms commonly used in robotics are obtained as structural solutions from plane linkages with five degrees of freedom, in which the basis and effector are nominated and two active kinematic pairs of the system are positioned. The basis and the effector are determined by inverse structural modeling, the inverse model consisting exclusively of passive modular groups. It is obtained by connecting the effector with plane motion dependent on two independent parameters through a virtual kinematic pair at the basis canceling the degree of mobility. The placement of active pairs is achieved by direct structural modeling, the direct model consisting of active and, eventually, passive modular groups. A mechanism performing with precision and accuracy of motion must have the inverse model and the direct model consisting of a minimum number of modular groups, as appropriate passive or active ones. The optimal inverse model is always a Baranov truss, from which the elimination of the basis results a single passive modular group. Bi-mobile mechanisms with three independent contours are obtained from the 40 kinematic chains with five degrees of freedom and three independent contours mentioned in the literature [Appendix 1]. They have a number of 8 mobile elements and 11 lower kinematic pairs, and the optimal inverse models, characterized by 9 elements and 12 kinematic pairs being Baranov trusses. The number of passive modular groups with 8 elements obtained from a Baranov truss with nine elements is $C_9^8 = C_9^1 = 9$, from which indistinct solutions due to symmetrical elements are eliminated. Thus, there are 188 structures, of which 95 ones are found in the solutions of the inverse models mentioned and are specially marked.

Key words: bi-mobile linkage, bi-mobile robot mechanism, optimal solution, baranov truss, passive modular group, inverse modelling, direct modelling.

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Ro. J. Techn. Sci. − Appl. Mechanics, Vol. 69, N° 1, P. 75–88, Bucharest, 2024
DOI:10.59277/RJTS-AM.2024.1.04

1. INTRODUCTION

The structural synthesis of bi-mobile plane mechanisms based on kinematic chains with five degrees of freedom required the selection of base and effector elements in the chain, achieved by inverse modeling [6, 7, 11]. The virtual connection to the base of the effector with plane motion dependent on two independent parameters [8, 11] leads to the cancellation of the mobility of the structure. The solutions are recorded in a base – effector square and symmetric matrix (nxn) with Boolean values in which n signifies the number of elements of the chain [8].

In previous papers, inverse models have been analyzed. Due to the degree of null mobility, there are constituted by passive modular groups (Assur). In the case of linkages with 9 elements and three independent contours, the inverse model can have one of the following passive structures: 2+2+2+2, 2+2+4, 2+4+2, 4+2+2, 2+6, 6+2, 8 [7,8]. The optimal inverse models are equivalent to Baranov trusses with 9 links, which have a single passive modular group with 8 elements. Such modular groups are found in literature exclusively in the case of structural models dedicated to the selection of the base and effector of bi-mobile mechanisms [1–4, 12–23].
The number of passive modular groups with 8 elements obtained from a Baranov truss with nine elements is $C_9^8 = C_9^1 = 9$, from which non-distinct solutions due to symmetric elements are retained. This paper includes aspects related to these passive modular groups of structural modular inverse models.

In the classical mechanism theory literature the first passive modular groups were used in the structural analysis and synthesis of plane mechanisms, especially mono-mobiles using their fundamental (Assur) principle of formation. These were correlated with the Baranov trusses with three links (BT 1), five (BT 2, BT3) and seven ones (BT 4, BT 5) from which they are deduced.

In recent years, Baranov trusses have come to the attention of researchers [4]. The structural synthesis of bi-mobile plane mechanisms based on kinematic chains with five degrees of freedom required the selection of base and effector elements in the chain, achieved by inverse modeling [8–11].

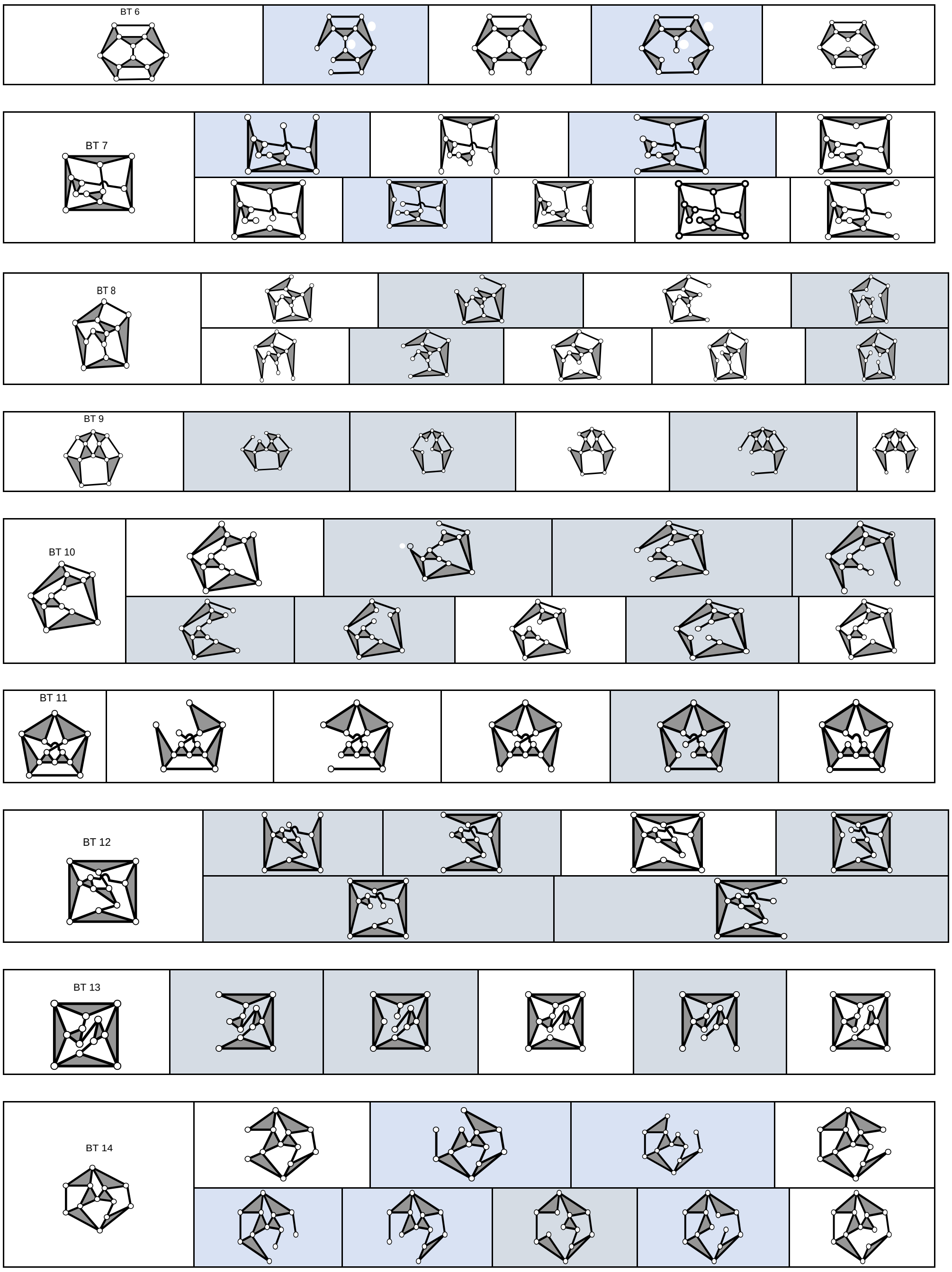
The advantage of such a structure lies in the high precision with which the trajectory of the effector end is achieve.

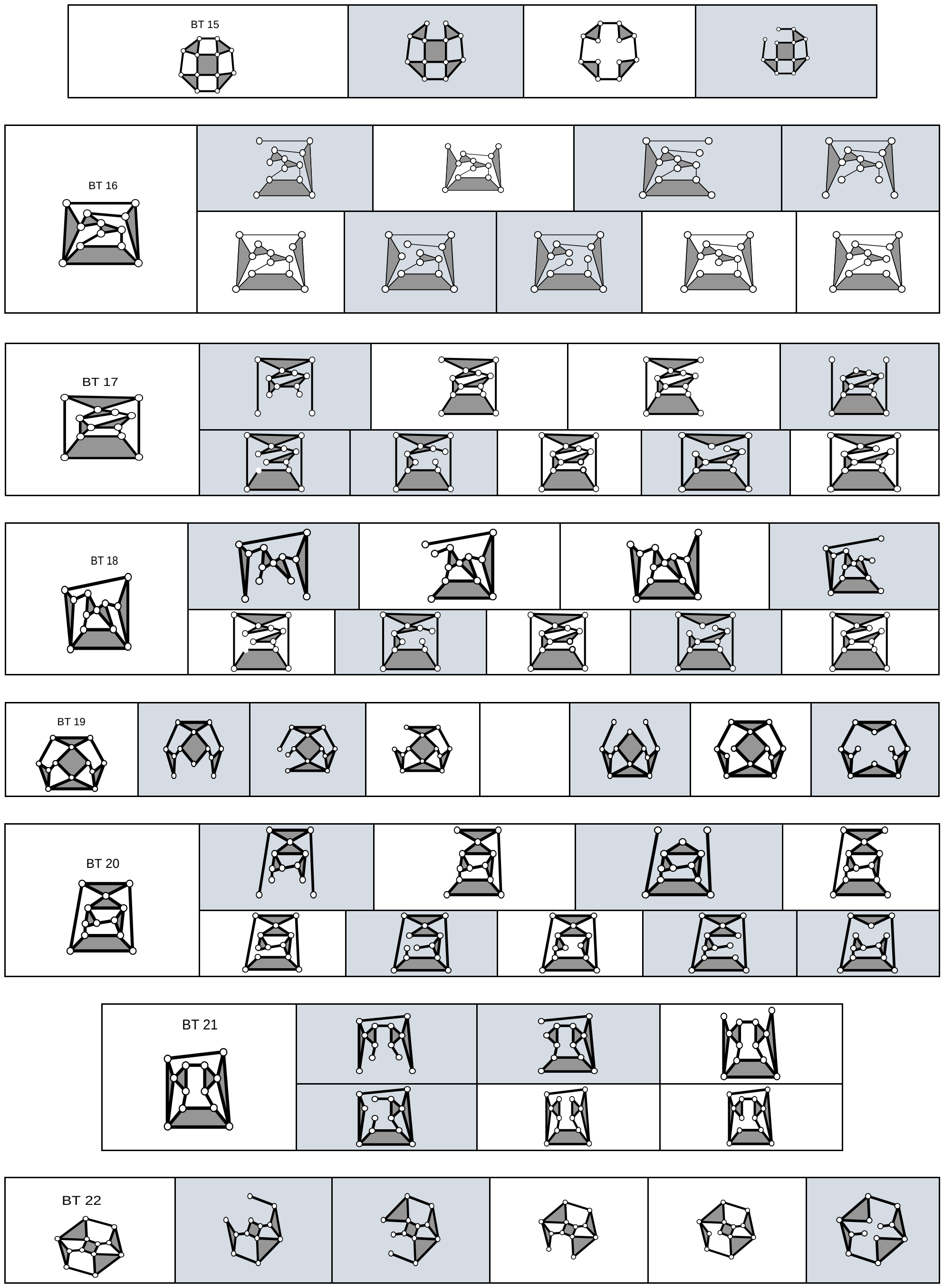
2. STRUCTURAL SOLUTIONS FOR PASSIVE GROUPS WITH EIGHT ELEMENS

Passive modular groups with eight elements are obtained as structural solutions from Baranov trusses with 9 elements named BT6 – BT33. These are shown in Table 1, which synthesizes the distinct ones for each of them, marked those found in the inverse models of bi-mobile mechanisms and three independent contours.

Table 1

Passive modular groups with eight elements

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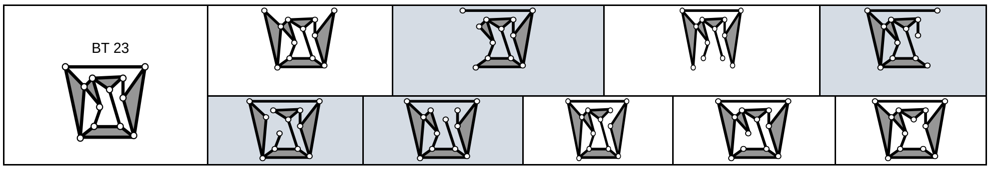
BT 16
BT 17
BT 18
BT 19
BT 20
BT 21
BT 22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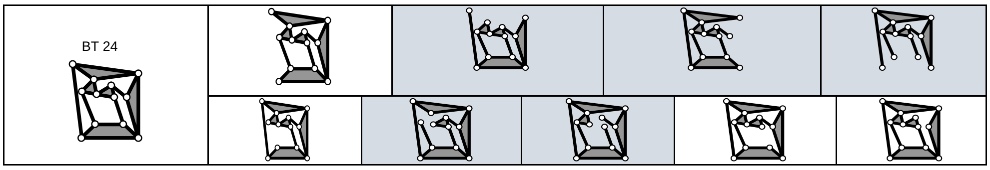
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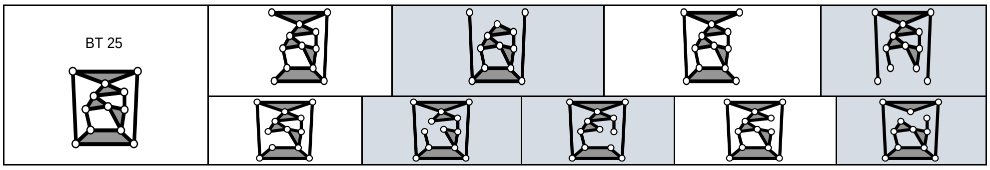
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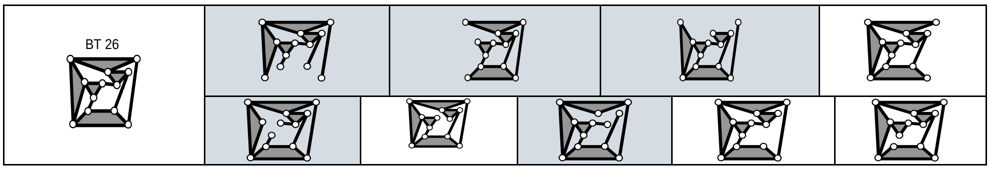
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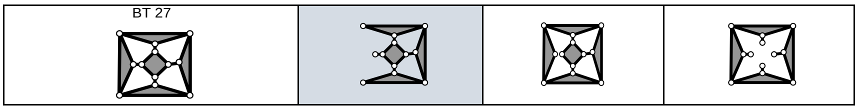
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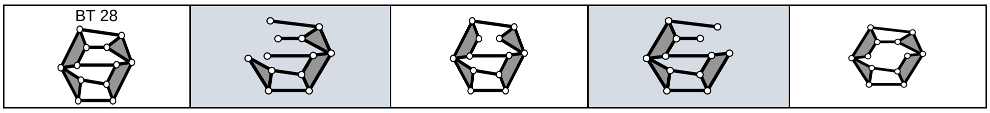
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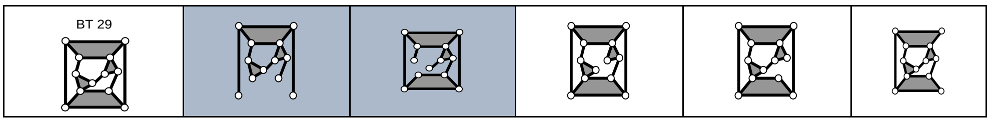
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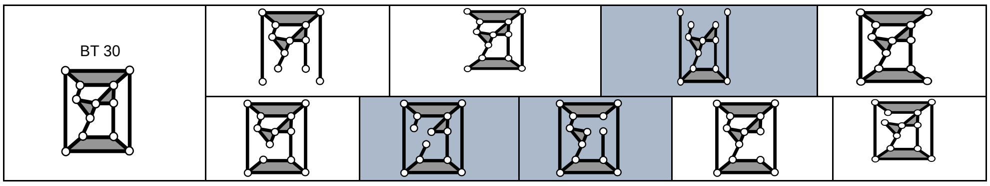
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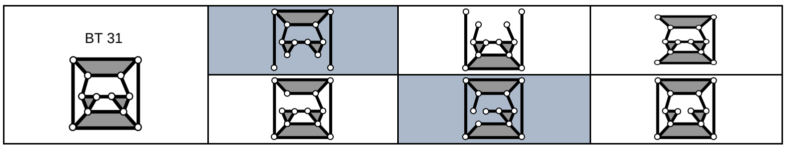
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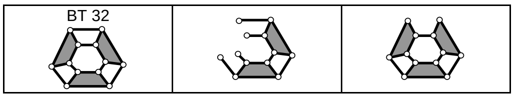
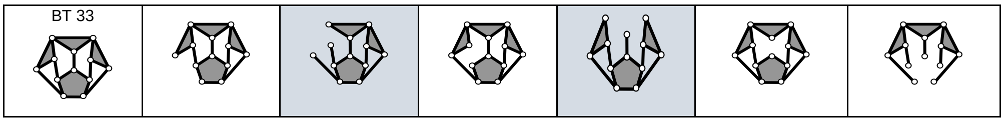




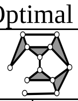
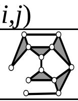
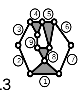
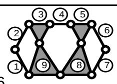
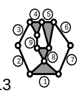
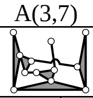
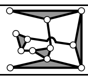
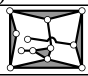
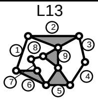
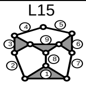
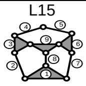
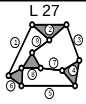
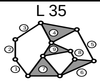
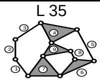
Consequently, from the Baranov BT6 – BT33 trusses with 8 elements emerge 188 passive modular groups with 9 elements, 95 of which are found in the optimal inverse models of bi-mobile mechanisms and three independent contours exposed below.

3. PASSIVE GROUPS WITH EIGHT LINKS APPLIED TO OPTIMAL INVERSE MODELS OF BI-MOBILE AND THREE LOOPED MECHANISMS

Following the solutions of the passive groups highlighted in Table 1, the optimal base-effector solutions $A(i,j)$ for bi-mobile mechanisms and three independent contours (Table 2) obtained by inverse modelling of the L_j related kinematic chains [appendix 1].

Table 2

Passive modular groups with eight elements in optimal structural solutions for basis-effector

<table>
<tr><td rowspan="3"></td><td rowspan="3">Baranov truss</td><td colspan="6">Passive structural groups with 8 elements</td></tr>
<tr><td colspan="6">Kinematic linkage L_j</td></tr>
<tr><td colspan="6">Optimal basis i – effector j solutions $A(i,j)$</td></tr>
<tr><td rowspan="3">1.</td><td rowspan="3">BT 6</td><td colspan="4"></td><td colspan="2"></td></tr>
<tr><td colspan="2">L3 </td><td colspan="2">L6 </td><td colspan="2">L3 </td></tr>
<tr><td colspan="2">A(3,7)</td><td colspan="2">A(2,6)</td><td colspan="2">A(7,3)</td></tr>
<tr><td rowspan="2">2.</td><td rowspan="2">BT 7</td><td colspan="2"></td><td colspan="3"></td><td></td></tr>
<tr><td>L13 </td><td>L15 </td><td>L15 </td><td>L 27 </td><td>L 35 </td><td>L 35 </td></tr>
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		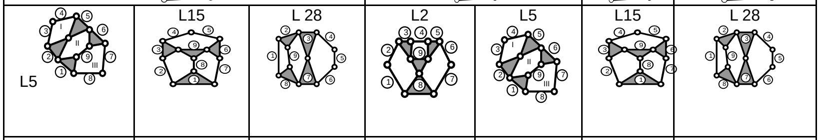
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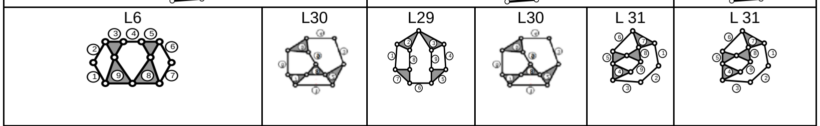
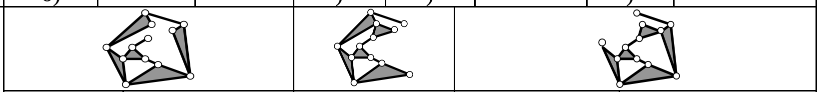
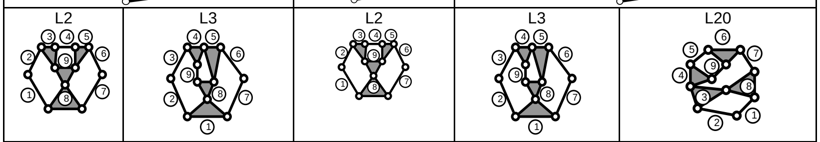
4.	BT 9	
		
		4A(1,6) A(6,1) A(1,7) A(3,9) A(1,4) A(9,3) A(6,2) A(2,6)
5.	BT 10	
		
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		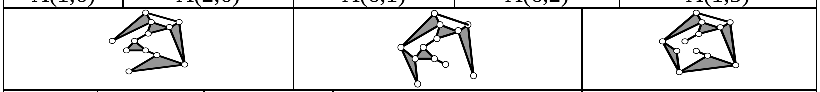
		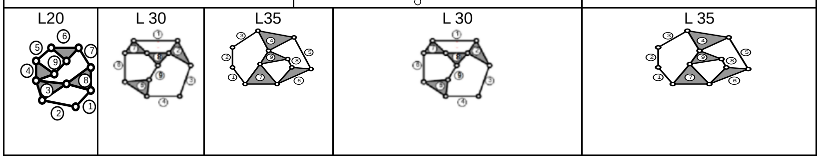
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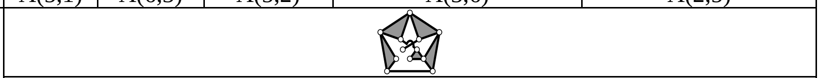
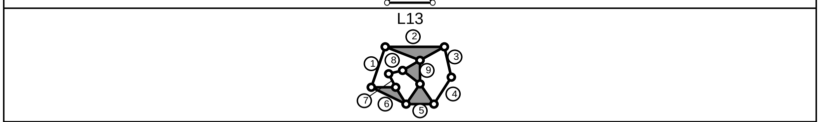
6.	BT 11	
		
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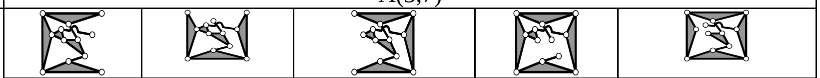
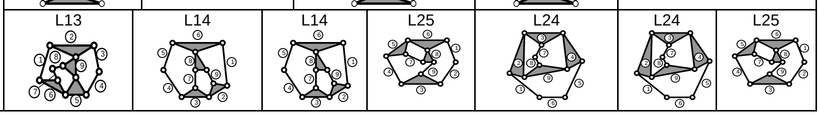
7.	BT 12	
		

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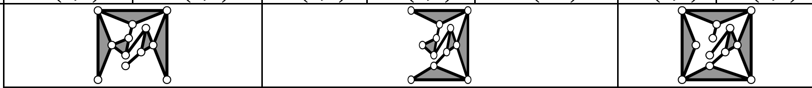
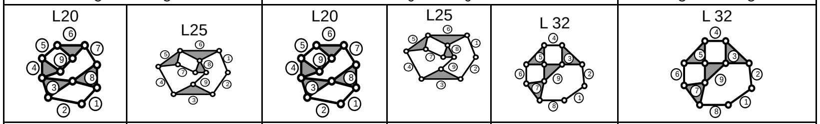
8.	BT 13	
		
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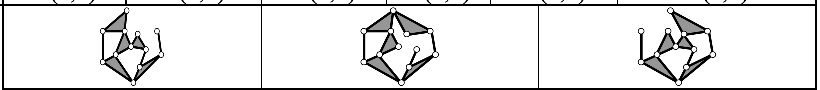
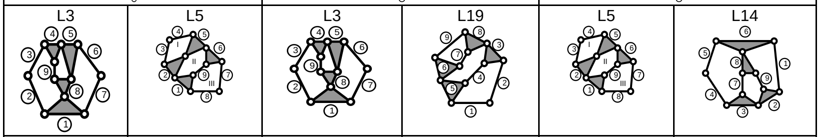
9.	BT 14	
		
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		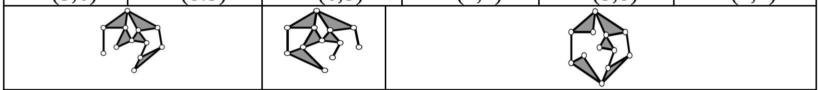
		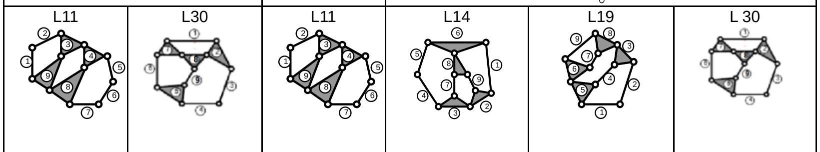
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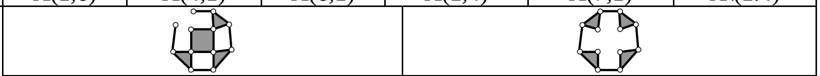
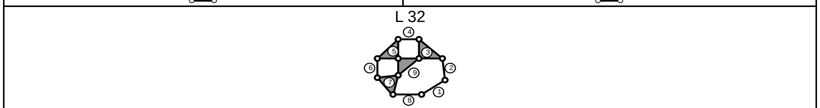
10.	BT 15	
		
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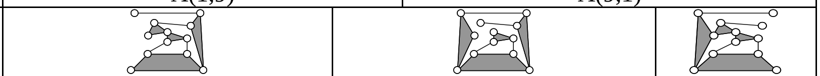
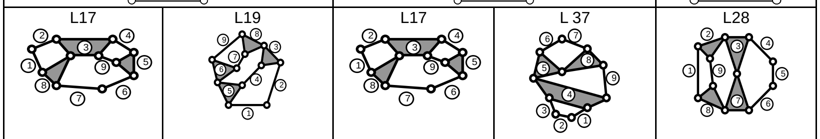
	BT 16	
		
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		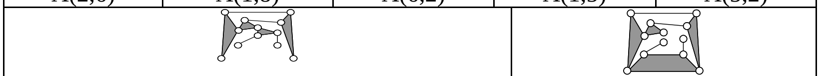
		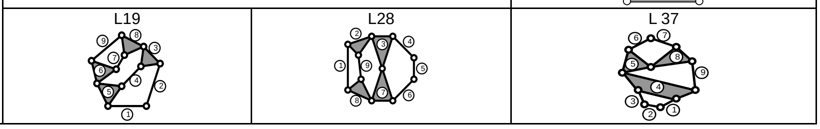

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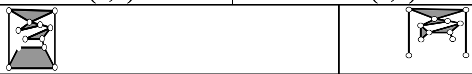
12.	BT 17						
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		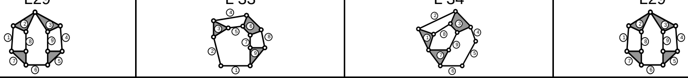					
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		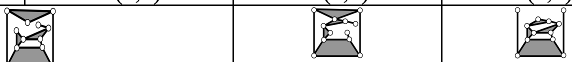					
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		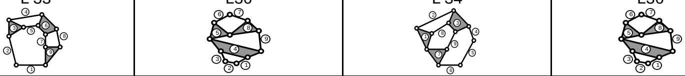					
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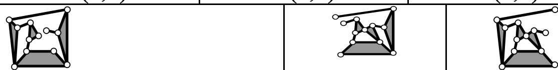
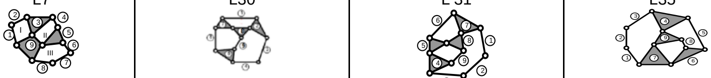
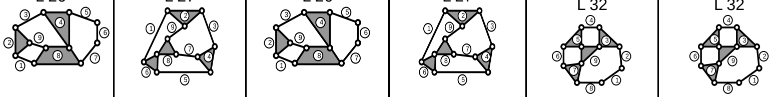
13.	BT 18						
		L7	L30	L 31	L35		
							
		A(1,7)	A(4,8)	A(2,5)	A(2,9)		
							
		L7	L30	L 31	L35		
							
		A(7,1)	A(8,4)	A(5,2)	A(9,2)		
14.	BT 19						
		L 26	L 27	L 26	L 27	L 32	L 32
							
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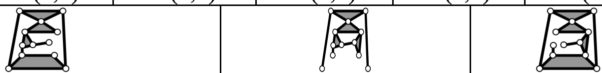
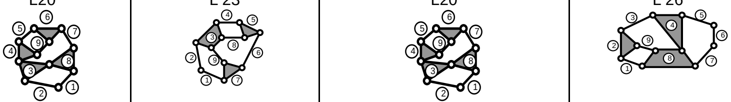
15.	BT 20						
		L20	L 23	L20	L 26		
							
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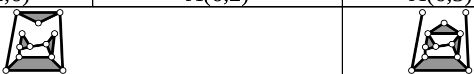
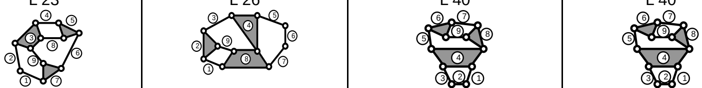
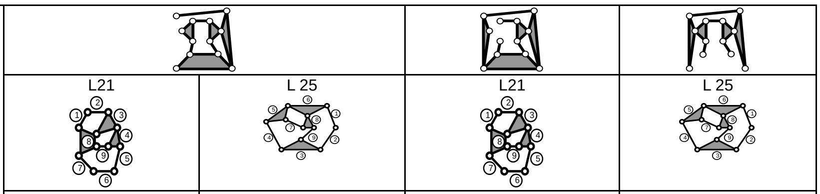
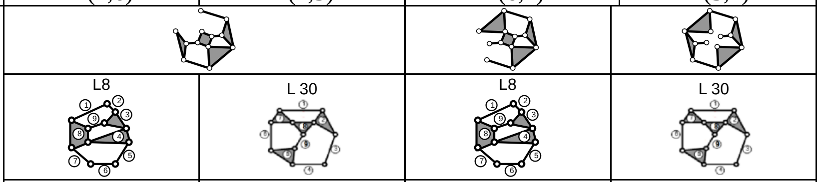
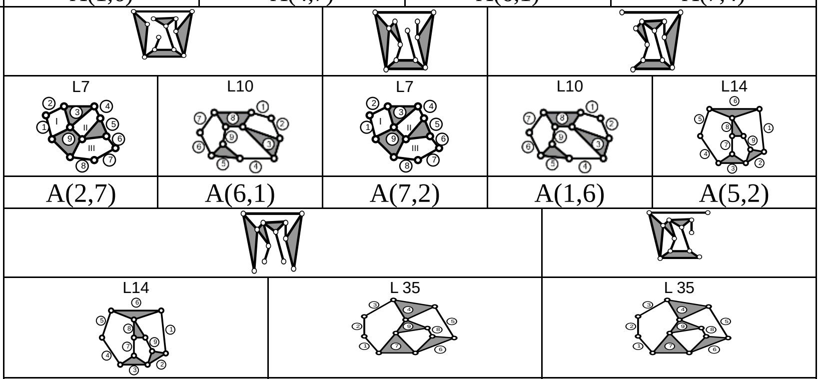
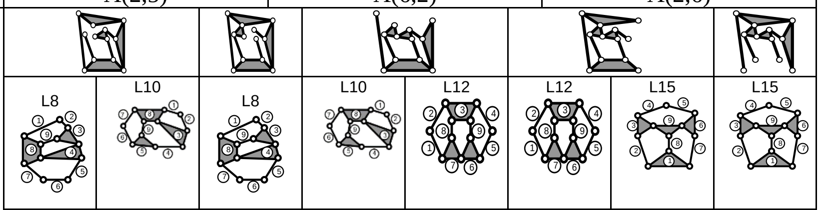
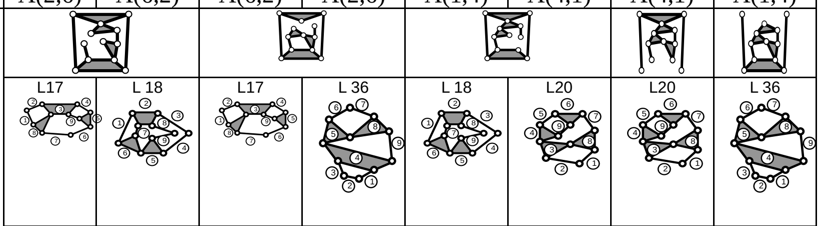
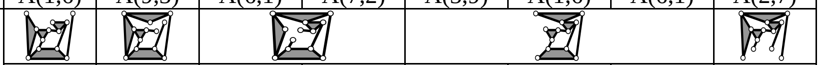
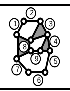
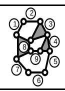
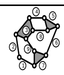
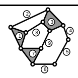
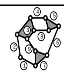
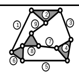
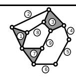
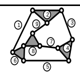
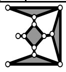
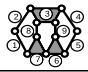
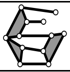
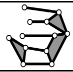
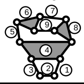
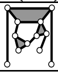
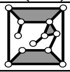
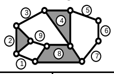
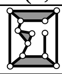
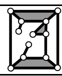
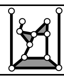
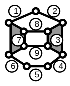
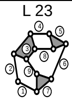
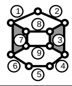
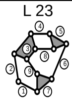
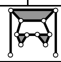
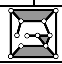
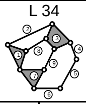
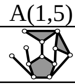
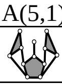
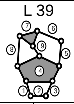
							
		L 23	L 26	L 40	L 40		
							
		A(6,2)	A(3,6)	A(7,2)	A(2,7)		

16.	BT21		L21, L 25, L21, L 25 A(1,6), A(2,5), A(6,1), A(5,2)
17.	BT22		L8, L 30, L8, L 30 A(1,6), A(4,7), A(6,1), A(7,4)
18.	BT23		L7, L10, L7, L10, L14 A(2,7), A(6,1), A(7,2), A(1,6), A(5,2) L14, L 35, L 35 A(2,5), A(6,2), A(2,6)
19.	BT 24		L8, L10, L8, L10, L12, L12, L15, L15 A(2,6), A(6,2), A(6,2), A(2,6), A(1,4), A(4,1), A(4,1), A(1,4)
20.	BT 25		L17, L 18, L17, L 36, L 18, L20, L20, L 36 A(1,6), A(9,3), A(6,1), A(7,2), A(3,9), A(1,6), A(6,1), A(2,7)
21.	BT 26		L21, L21, L 23, L 34, L 23, L 27, L 34, L 27

									
		A(2,6)	A(6,2)	A(1,4)	A(5,2)	A(4,1)	A(1,4)	A(2,5)	A(4,1)
22.	BT 27								
		L12 							
		A(1,5)							
23	BT 28								
		L 40 							
		A(2,6)				A(6,2)			
24	BT 29								
		L 26 							
		A(2,6)				A(6,2)			
25	BT 30								
		L22 		L 23 		L22 		L 23 	
		A(1,5)		A(1,5)		A(1,5)		A(5,1)	
26	BT31								
		L 34 							
		A(1,5)				A(5,1)			
27.	BT 33								
		L 39 							
		A(2,6)				A(6,2)			

Two manipulators (Fig. 1 and Fig. 2), obtained from solutions mentioned in Table 2 are designed.

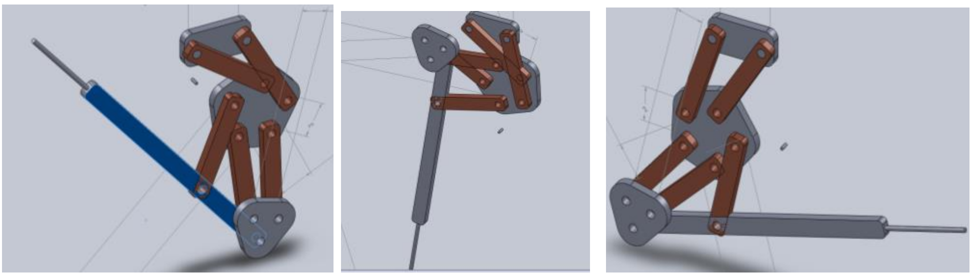


Fig. 1 – Manipulator based on linkage L39 with basis 2 and effector 6.

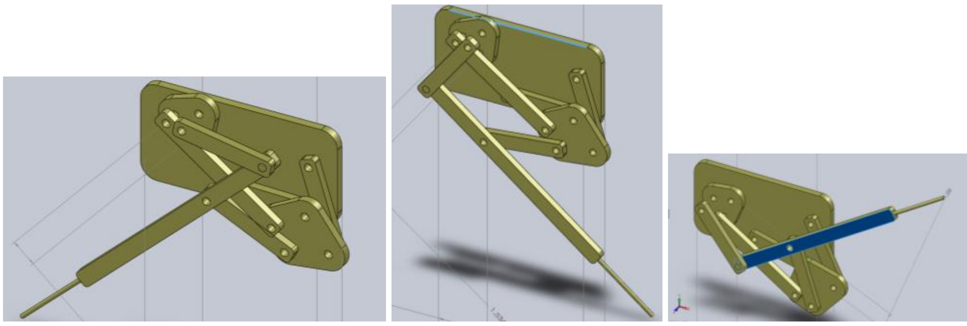


Fig. 2 – Manipulator based on linkage L34 with basis 1 and effector 5.

4. CONCLUSIONS

The paper highlights two aspects in close connection with the theory of mechanisms and robots.

Thus, the 13 passive modular groups called classic Assur groups obtained from Baranov BT1 – BT6 trusses are completed with the assembly of those with 8 elements detached from Baranov trusses B6 – B33 (Table 1). They were not interested in the synthesis of mechanisms and found their importance in inverse modeling of bi-mobile linkages and three independent contours, by which they nominate the base and effector for robot mechanisms with two degrees of mobility [5–8].

Also, the optimal base-effector solutions for bi-mobile robot mechanisms are highlighted, which are based on inverse modeling on passive modular groups with 8 elements (Table 2). They are an inexhaustible source of technical solutions for researchers and designers in the field. Two variants of robot mechanisms that fit these requirements are presented.

Received on March 12, 2024

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APPENDIX

Bi-mobile and three looped linkages