Layout design III.

Chapter 6

Layout generation

- MCRAFT
- BLOCPLAN
- LOGIC

Methods for layout design

- Layout generation
  - Construction algorithms
    - Building a block layout by iteratively adding departments
  - Improvements algorithms
    - Incrementally improving an initial block layout

Algorithm classification

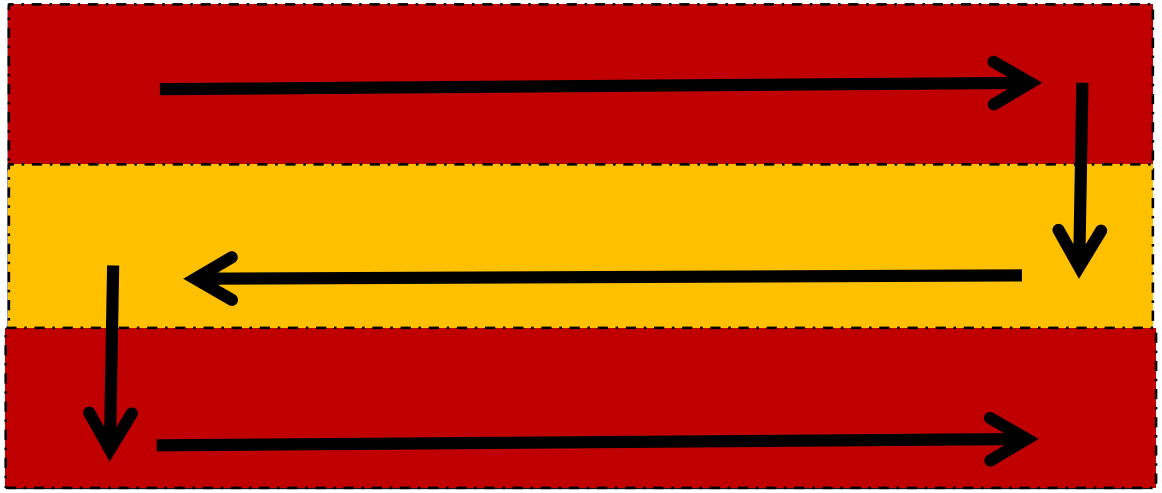
Construction algorithm	Improvement algorithm
Graph-based method ALDEP CORELAP PLANET	Pairwise exchange method CRAFT MCCRAFT MULTIPLE
BLOCPLAN LOGIC Mixed integer programming	

MCRAFT – Micro CRAFT

- An algorithm evolved from CRAFT allowing non-adjacent exchanges
- Shifts automatically other departments when unequal or non-adjacent departments are being exchanged
- Horizontal sweep patterns are used to
  - place departments
  - move departments while two departments are being exchanged

MCRAFT – Sweep pattern

- Layout is specified by a sequence of departments
- In each iteration, cells are formed starting from the top-left corner.
  - First department in the sequence is placed in the top-left corner.
  - If there is a space on the immediate right of the first department, next department in the sequence is placed. Otherwise the next row in the building is used to locate the rest of the department (the remaining cells) or the next department in the sequence.

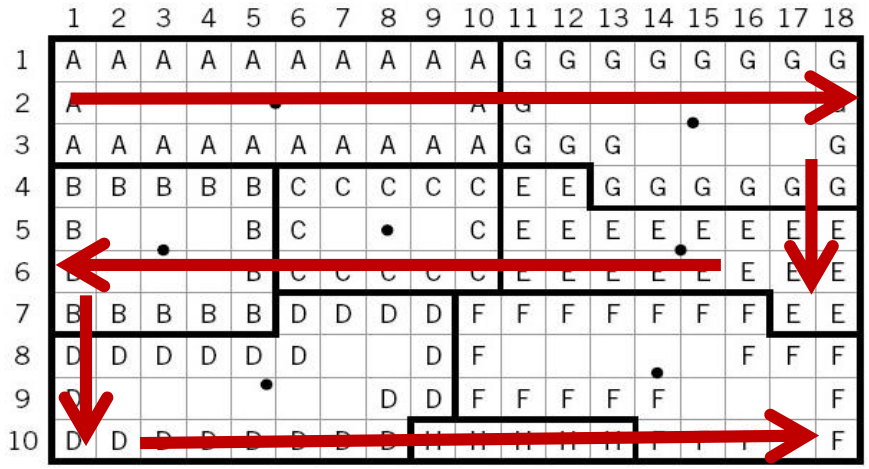


MCRAFT - procedure

1. MCRAFT requires the user to specify
   - Facility dimensions (rectangular, width x length)
   - Number of bands
2. After the band width is set, MCRAFT requires a **vector** (the sequence) of the departments in the initial layout. Based on this vector, it locates the departments following the serpentine flow directions
3. A swap/exchange selection procedure similar to that of CRAFT is implemented. **Not necessarily limited to adjacent or equal-size departments!!**
4. If any improving exchange is selected, then the two departments are swapped using a shifting procedure of the other departments.
5. REPEAT 3 and 4 until no improvement can be made.

MCRAFT - Example

- Same problem data as in the CRAFT example
- Facility dimensions:
  - 360ft X 200ft
  - Number of Bands: 3



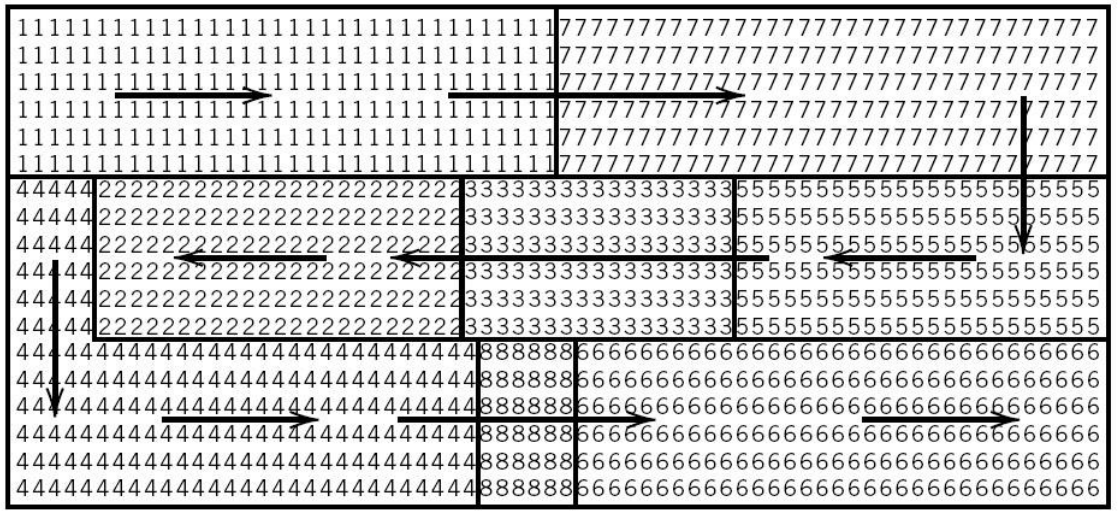
Initial Layout Vector:

1-7-5-3-2-4-8-6 (A-G-E-C-B-D-H-F)

MCRAFT - Example

- Initial layout

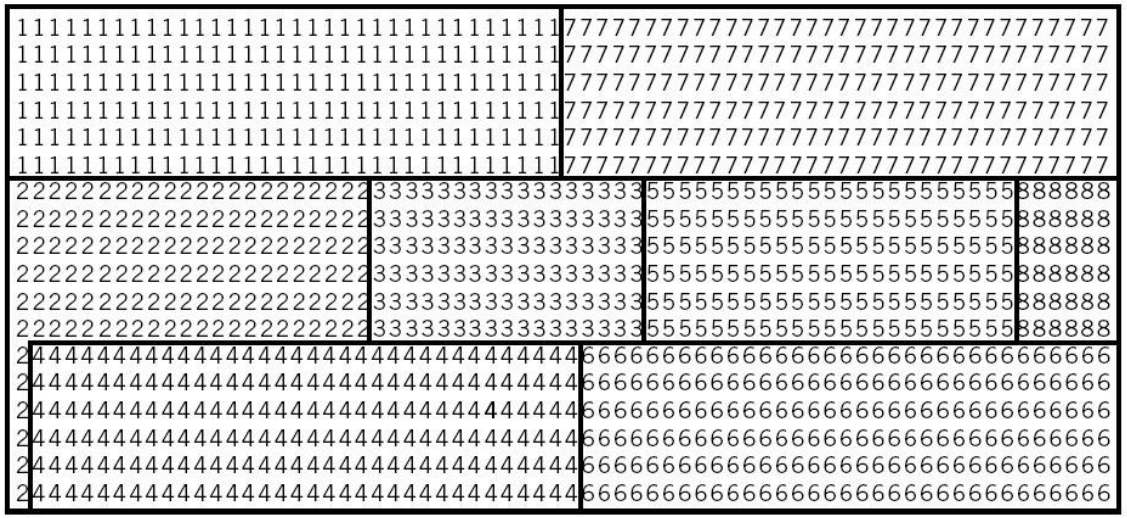
Layout Vector:
1-7-5-3-2-4-8-6



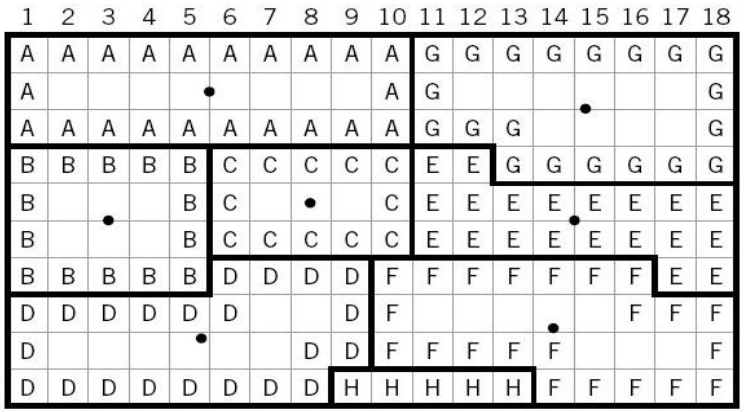
- Final layout

(after 4 iterations)

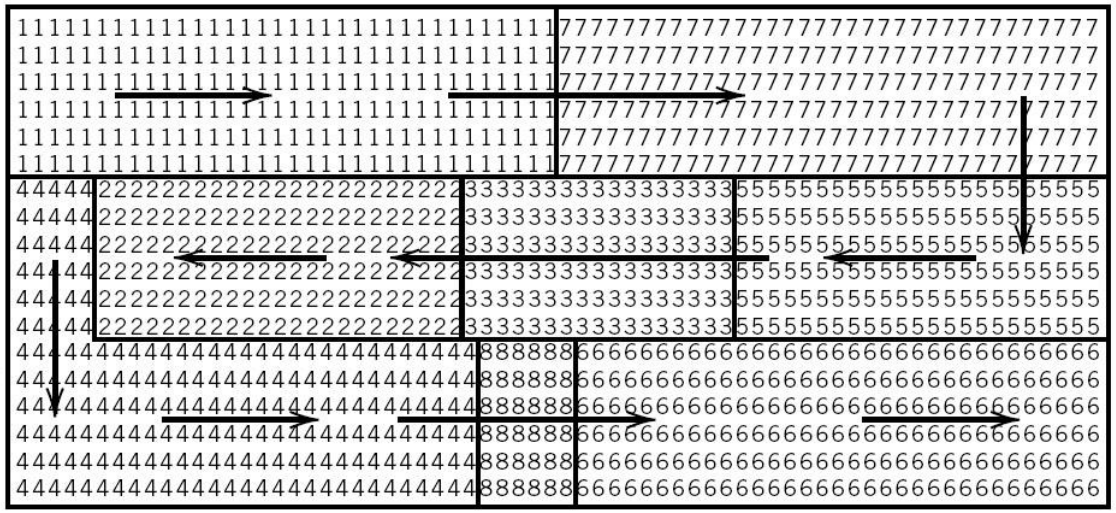
  - Shapes better than CRAFT
  - Try alternative layouts!



MCRAFT - Example



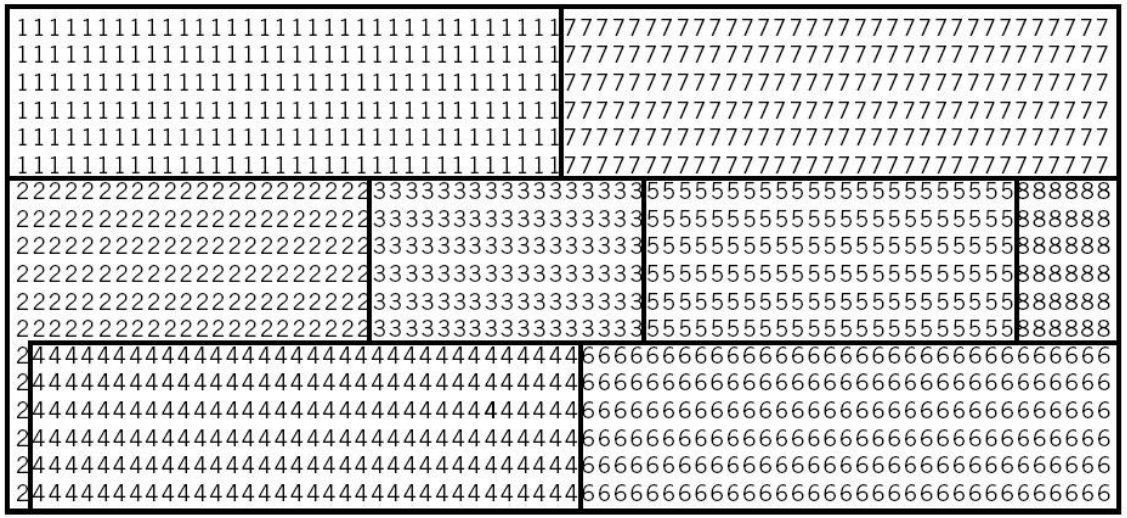
Layout Vector:
1-7-5-3-2-4-8-6



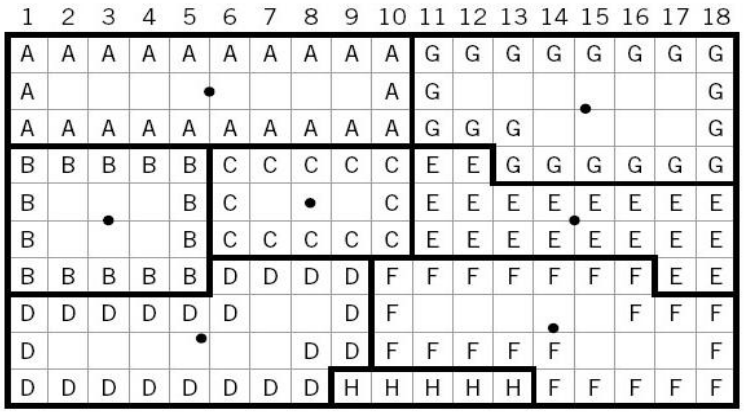
- Final layout

  (after 4 iterations)

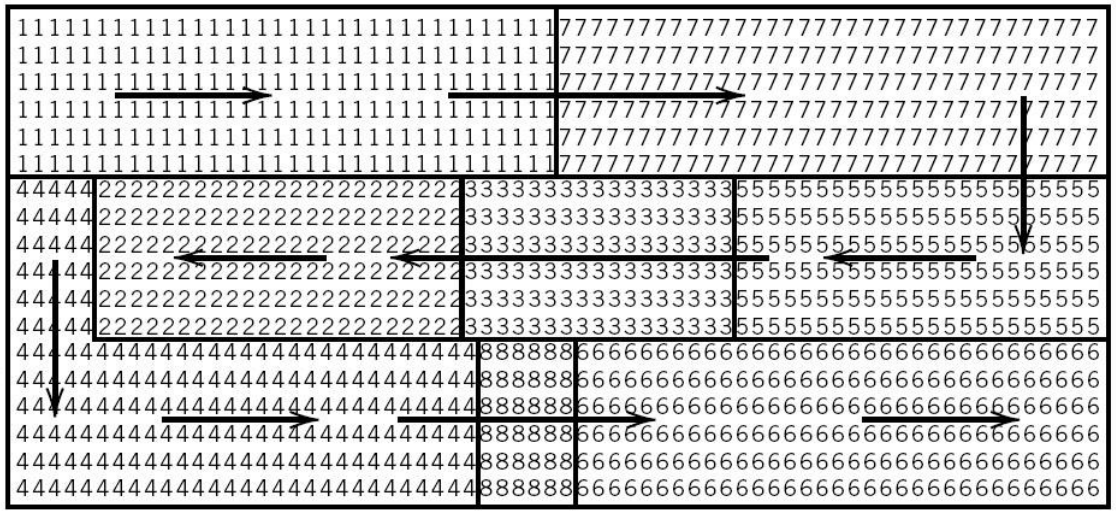
  - Shapes better than CRAFT
  - Try alternative layouts!

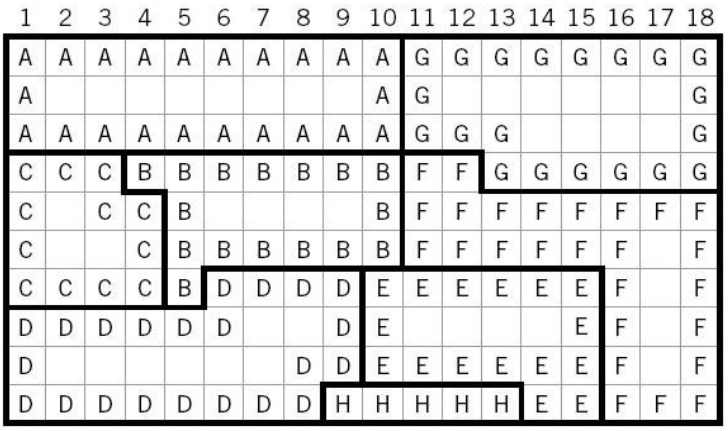


MCRAFT - Example

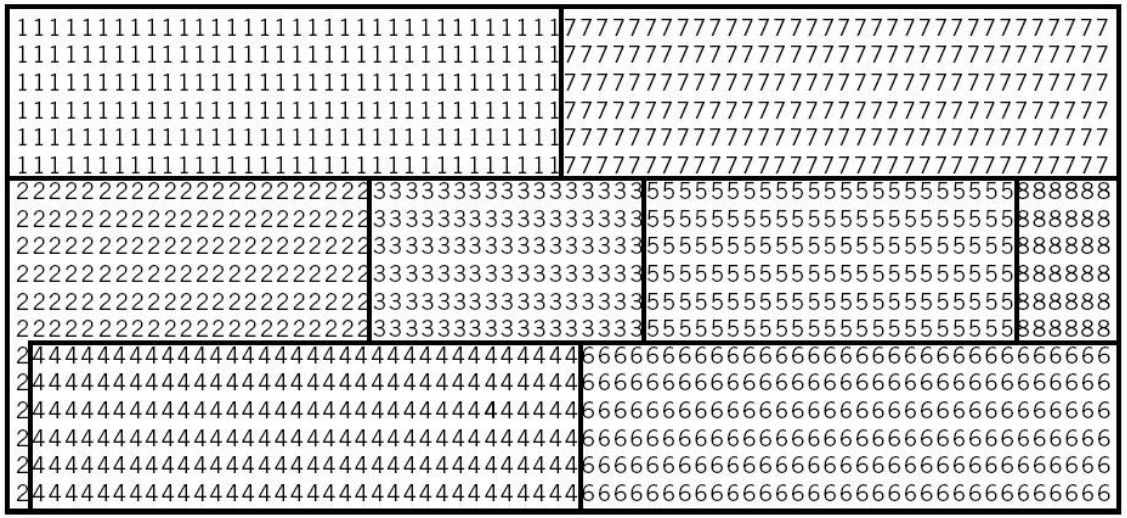


Layout Vector:
1-7-5-3-2-4-8-6



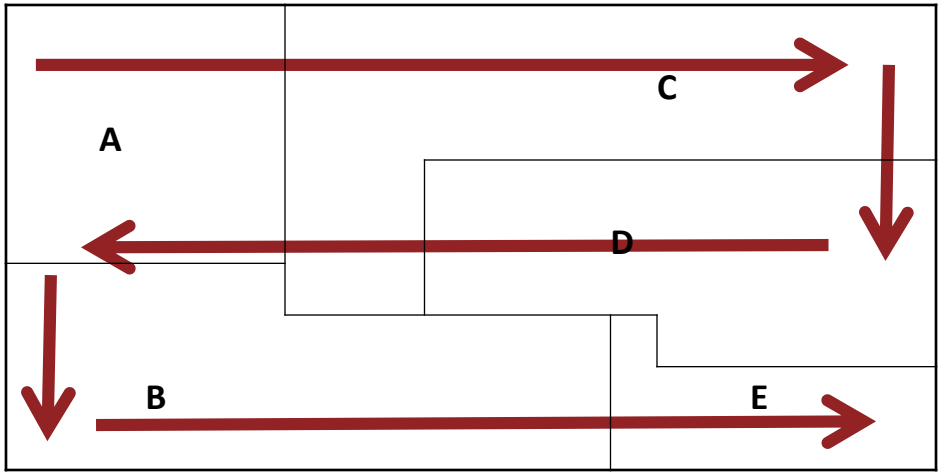


- Try alternative layouts!



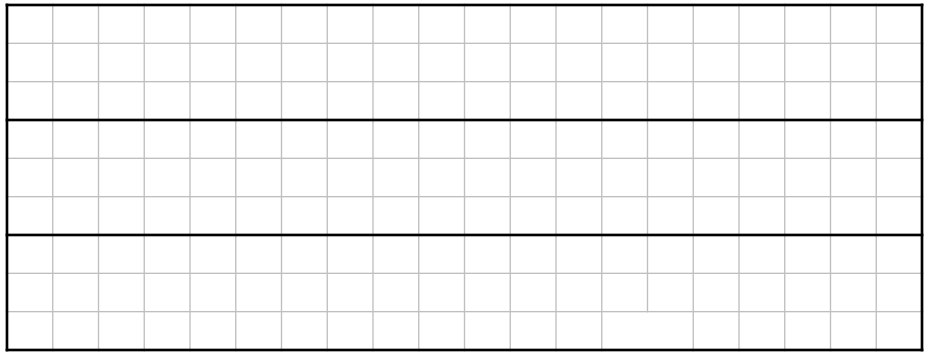
MCRAFT - Example

- A facility with the layout below has 5 departments. Their sizes are given below. An engineering team wants to use MCRAFT method in order to improve the existing layout. The building dimensions are 20m x 9m.
- Determine the layout vector and create an input layout for MCRAFT using 3 bands.



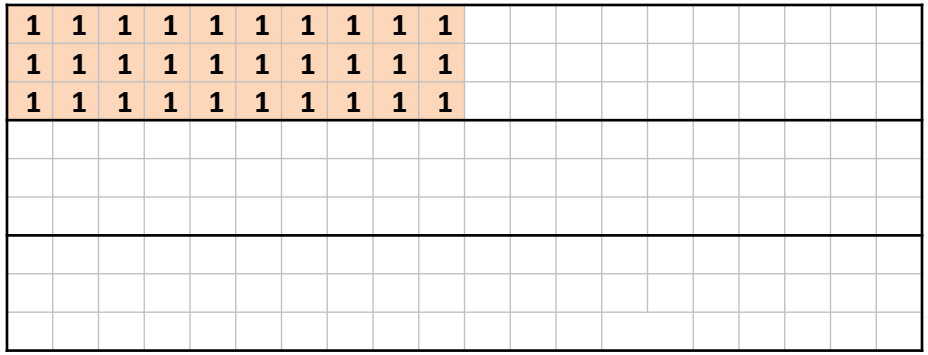
	Department size (m^2)
A	30
B	45
C	51
D	39
E	15

Layout vector is **1-3-4-2-5** (A-C-D-B-E)



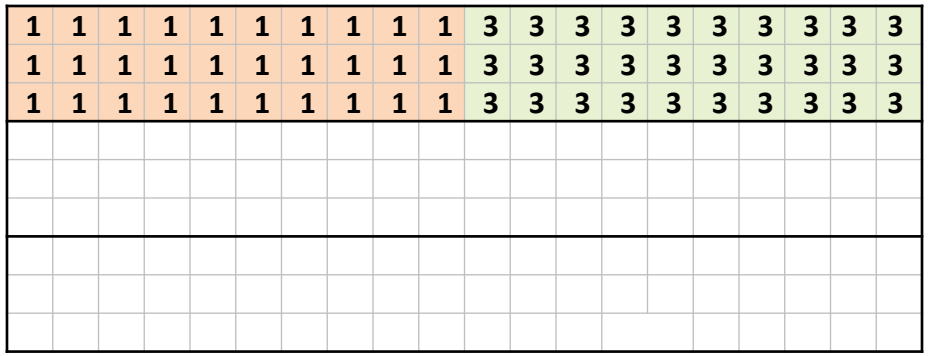
	Department size (m^2)
D1	30
D2	45
D3	51
D4	39
D5	15

Layout vector is **1-3-4-2-5**



	Department size (m^2)
D1	30
D2	45
D3	51
D4	39
D5	15

Layout vector is **1-3-4-2-5**



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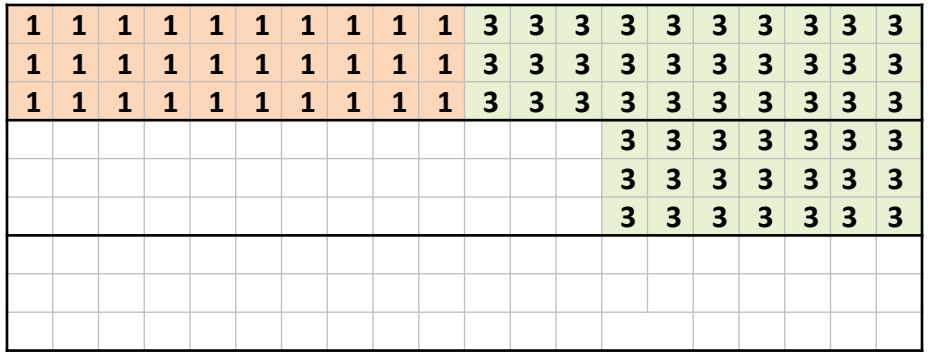
D5	15

Layout vector is **1-3-4-2-5**



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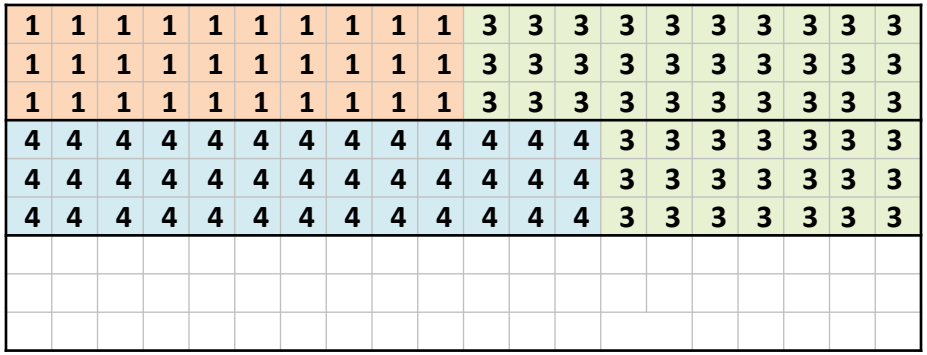

	Department size (m^2)
D1	30
D2	45
D3	51
D4	39
D5	15

Layout vector is **1-3-4-2-5**

1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3
1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3
1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5

	Department size (m^2)
D1	30
D2	45
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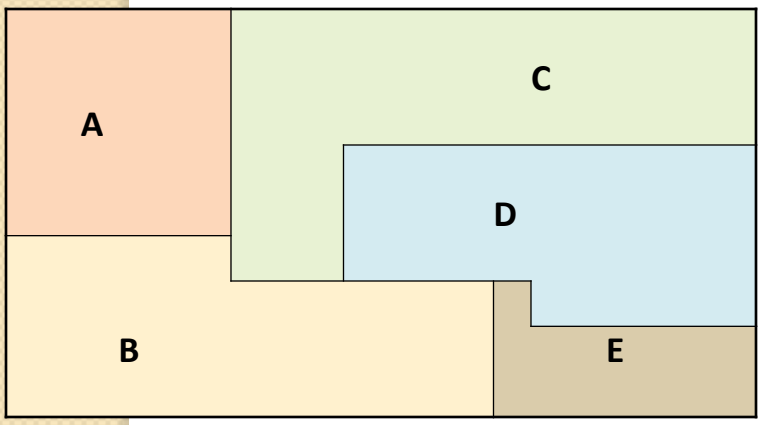
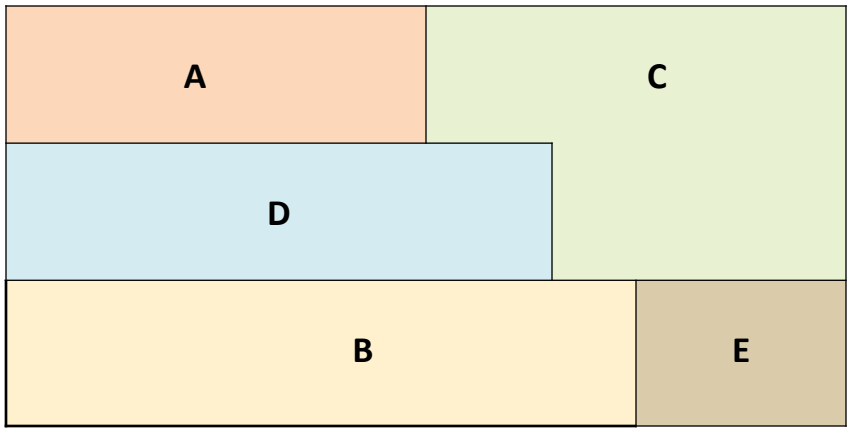
D4	39
D5	15

Layout vector is **1-3-4-2-5**



Real layout



Input used for MCRAFT

MCRAFT - Comments

- Strengths:
  - Unlike the CRAFT algorithm, it does not restrict the exchange to the adjacent cells
  - Smoother shapes compared to CRAFT (in most cases rectangular cells can be formed)
  - More exchange alternatives. The number of alternatives increases exponentially with the number of departments
  - Allows multi-floor layout planning

- Weaknesses:
  - Facility shape is a restriction
    - The initial layout cannot be captured accurately unless the departments are already arranged in bands
    - Band width is assumed to be the same for all the bands
  - MCRAFT is not as effective in treating fixed departments and obstacles (they can get shifted)

Input data

- Qualitative data
  - *Adjacency-based objective*
  - Input: **Relationship chart**
  - Algorithms:
    - Graph-based
    - CORELAP
    - ALDEP
- Quantitative data
  - *Distance-based objective*
  - Input: **From-to chart**
  - Algorithms:
    - Pairwise exchange
    - CRAFT
    - MCRAFT
    - MULTIPLE
- Both
  - Algorithms:
    - BLOCPLAN

BLOCPLAN

- Construction and improvement algorithm
- Distance-based and adjacency-based objective
- Departments are in bands (2 or 3 bands), but the band width may vary
- All departments are rectangular
- Continuous representation
- Input
  - From-To Chart
  - Relationship chart
- BLOCPLAN converts:
  - *From-to chart* to *Relationship chart* through Flow-between chart
  - *Relationship chart* to *numerical relationship chart* based on closeness ratings

From-To and Flow-Between Charts

Given M activities, a **From-To Chart** represents M(M-1) ***asymmetric*** quantitative relationships.

Example:

	D1	D2	D3
D1		f_{12}	f_{13}
D2	f_{21}		f_{23}
D3	f_{31}	f_{32}	

where

f_{ij} = material flow **from activity *i* to activity *j*.**

A **Flow-Between Chart** represents M(M-1)/2 ***symmetric*** quantitative relationships.

	D1	D2	D3
D1		g_{12}	g_{13}
D2			g_{23}
D3			

$g_{ij} = f_{ij} + f_{ji}$, for all $i > j$,

where

g_{ij} = material flow **between activities *i* and *j*.**

	D1	D2	D3
D1		$f_{12} + f_{21}$	$f_{13} + f_{31}$
D2			$f_{23} + f_{32}$
D3			

BLOCPLAN (quantitative → qualitative)

From-to-chart → Relationship chart

- Procedure:
  - BLOCPLAN creates ***Flow Between Chart***
  - The highest value in the matrix is *divided by 5*
  - The flow values in Flow Between Chart are divided by the resulting value and *5 intervals* are created
  - Five intervals correspond to five relationships *A, E, I, O and U*
  - *Relationship Chart* is created
  - This is a *BLOCPLAN-specific* procedure

BLOCPLAN (qualitative → quantitative)

Relationship chart → Numerical relationship chart

- Procedure:
  - Based on the selected closeness ratings transform the alphabetical values in Relationship diagram to numerical values
  - For example: A=10, E=5, I=2, O=1, U=0 and X=-10

	D1	D2	D3	D4	D5	D6
D1		A	I		I	
D2				E	E	O
D3					A	X
D4						
D5						O
D6						

Relationship chart

	D1	D2	D3	D4	D5	D6
D1		10	2		2	
D2				5	5	1
D3					10	-10
D4						
D5						1
D6						

Numerical relationship chart

BLOCPLAN

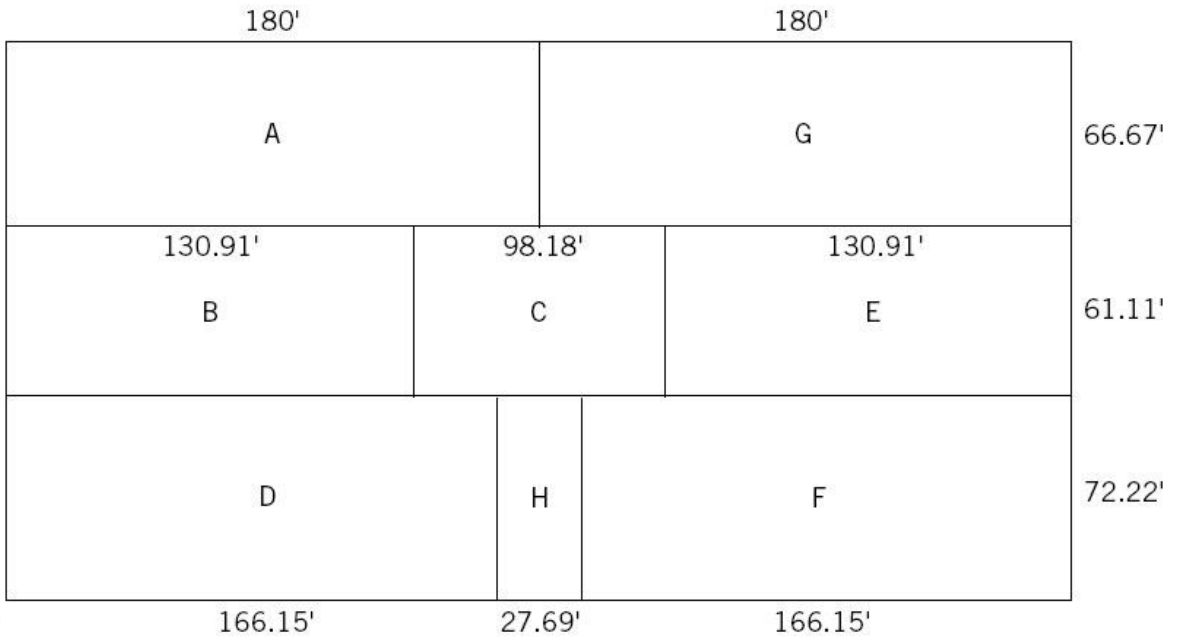
Example 1

- BLOCPLAN has proposed an improved layout for your existing facility. Given the Flow-to chart below calculate the adjacency and normalized adjacency scores for both and determine whether the proposed layout is more suitable. Use these closeness ratings: A=10, E=5, I=2, O=1, U=0 and X=-10

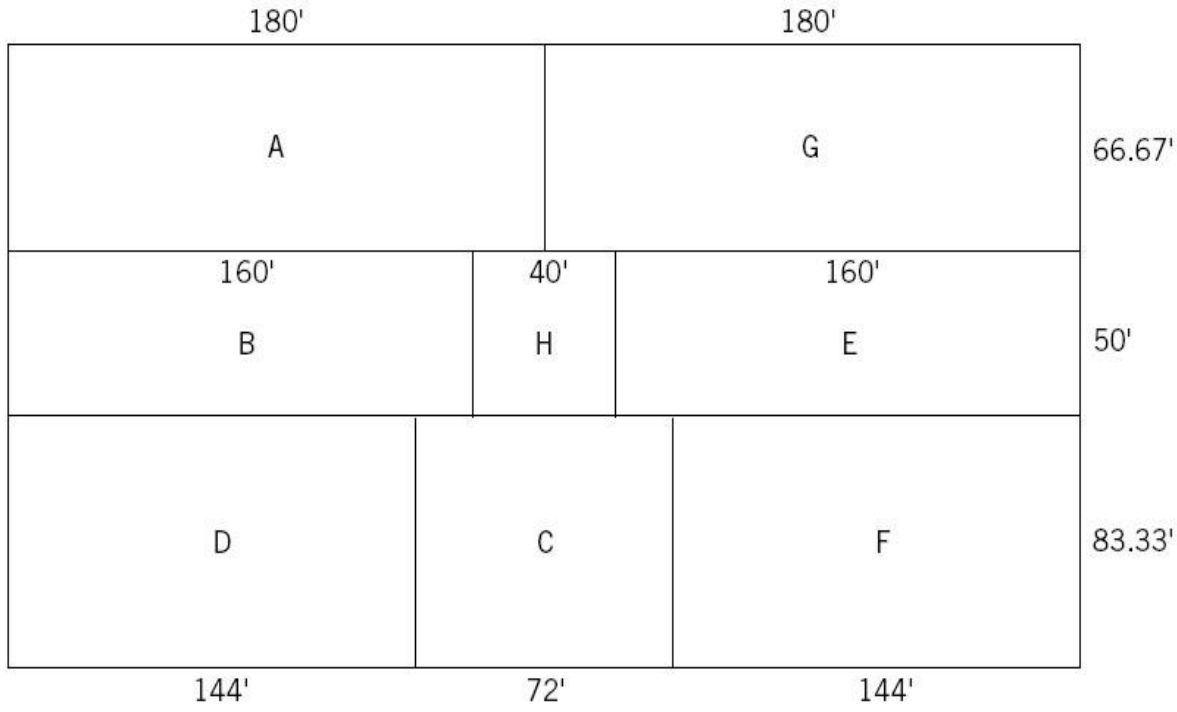
Department Name	FLOW							
	A	B	C	D	E	F	G	H
A: Receiving	0	45	15	25	10	5	0	0
B: Milling	0	0	0	30	25	15	0	0
C: Press	0	0	0	0	5	10	0	0
D: Screw m/c	0	20	0	0	35	0	0	0
E: Assembly	0	0	0	0	0	65	35	0
F: Plating	0	5	0	0	25	0	65	0
G: Shipping	0	0	0	0	0	0	0	0
H: Dummy	0	0	0	0	0	0	0	0

BLOCPLAN Example 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A	A	A	A	A	A	A	A	A	A	G	G	G	G	G	G	G	G
A				•					A	G				•			G
A	A	A	A	A	A	A	A	A	A	G	G	G					G
B	B	B	B	B	C	C	C	C	C	E	E	G	G	G	G	G	G
B		•		B	C		•		C	E	E	E	E	E	E	E	E
B				B	C	C	C	C	C	E	E	E	E	•	E	E	E
B	B	B	B	B	D	D	D	D	F	F	F	F	F	F	F	E	E
D	D	D	D	D	D			D	F				•		F	F	F
D				•			D	D	F	F	F	F	F				F
D	D	D	D	D	D	D	D	H	H	H	H	H	F	F	F	F	F



Final layout of the facility created by BLOCPLAN



BLOCPLAN
Example 1

Department Name	FLOW							
	A	B	C	D	E	F	G	H
A: Receiving	0	45	15	25	10	5	0	0
B: Milling	0	0	0	30	25	15	0	0
C: Press	0	0	0	0	5	10	0	0
D: Screw m/c	0	20	0	0	35	0	0	0
E: Assembly	0	0	0	0	0	65	35	0
F: Plating	0	5	0	0	25	0	65	0
G: Shipping	0	0	0	0	0	0	0	0
H: Dummy	0	0	0	0	0	0	0	0

From-to chart

	A	B	C	D	E	F	G	H
A	0	45	15	25	10	5	0	0
B		0	0	50	25	20	0	0
C			0	0	5	10	0	0
D				0	35	0	0	0
E					0	90	35	0
F						0	65	0
G							0	0
H								0

Flow-between chart

BLOCPLAN

Example 1

- The highest value is 90 => 90/5=18
- Intervals:
  - 73 to 90 units …..A
  - 55 to 72 units …..E
  - 37 to 54 units …..I
  - 19 to 36 units …..O
  - 0 to 18 units …….U

	A	B	C	D	E	F	G	H
A	0	45	15	25	10	5	0	0
B		0	0	50	25	20	0	0
C			0	0	5	10	0	0
D				0	35	0	0	0
E					0	90	35	0
F						0	65	0
G							0	0
H								0

	A	B	C	D	E	F	G	H
A	—	I	U	O	U	U	U	U
B		—	U	I	O	O	U	U
C			—	U	U	U	U	U
D				—	O	U	U	U
E					—	A	O	U
F						—	E	U
G							—	U
H								—

Flow-between chart  Relationship chart

BLOCPLAN
Example 1

- **Adjacency-based score**
  - Initial layout: z=15
  - Final layout: z=15

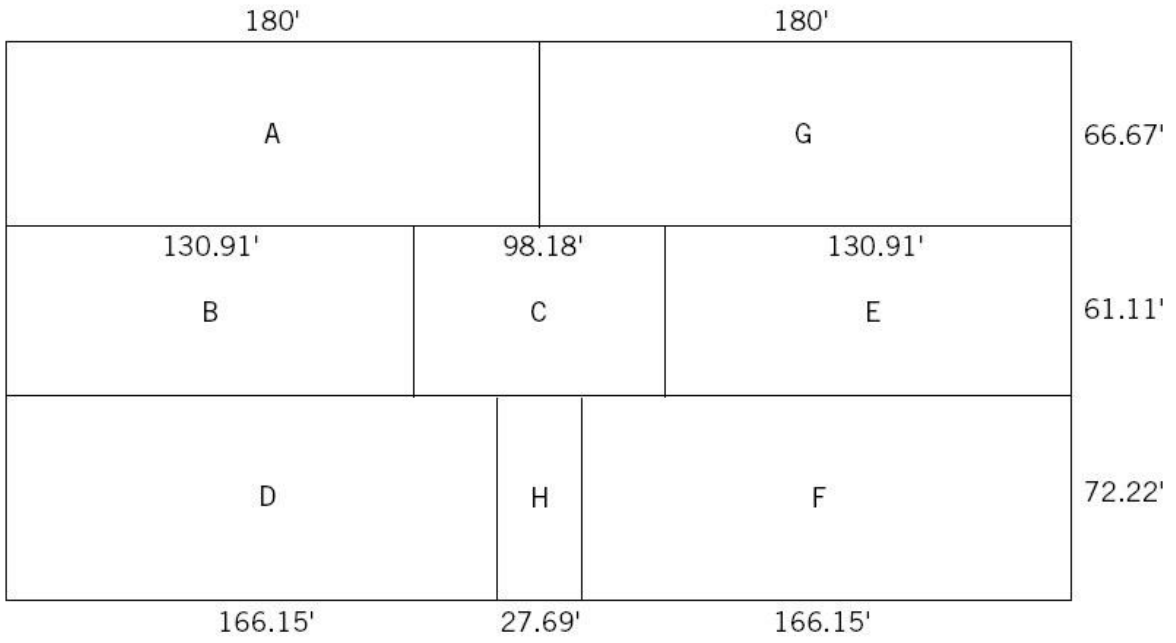
$$z = \sum_{i=1}^{m} \sum_{j=i+1}^{m} f_{ij} x_{ij}$$

- **Normalized adjacency score (efficiency rating)**
  - Initial layout: z=15/24=0.63
  - Final layout: z=15/24=0.63

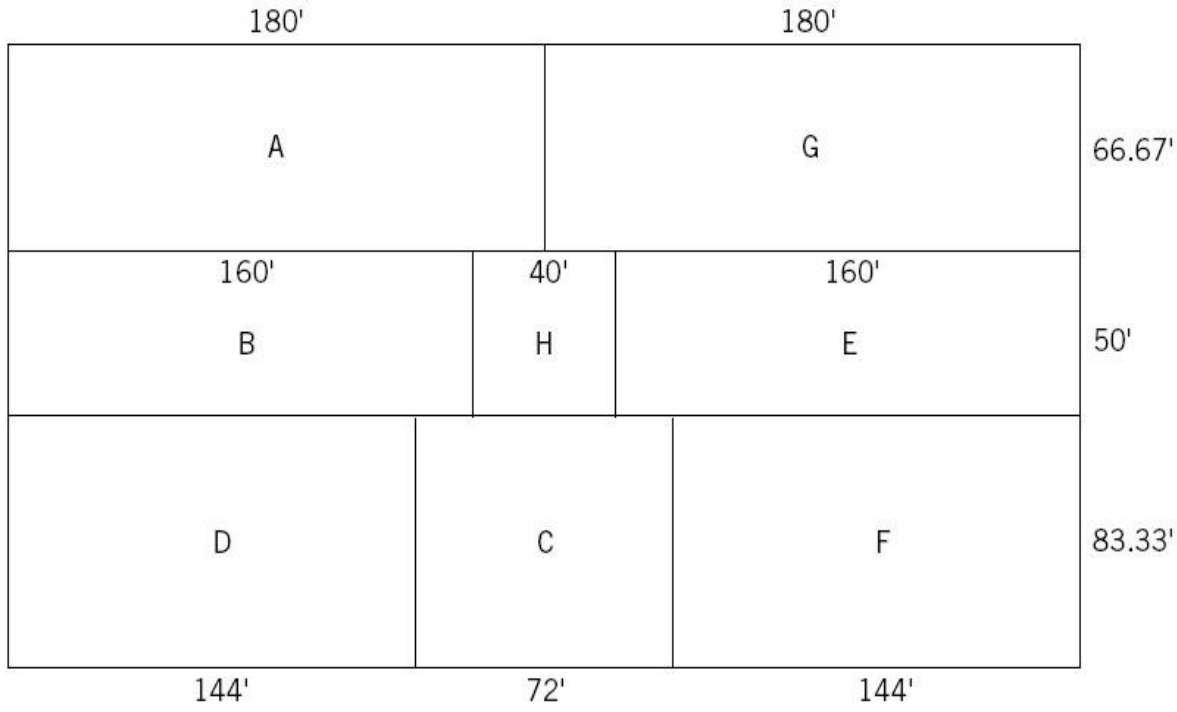
$$z = \frac{\sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} x_{ij}}{\sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij}}$$

BLOCPLAN Example 1

Initial layout of the facility



Final layout of the facility created by BLOCPLAN



BLOCPLAN
Example 1

- **Adjacency-based score**
  - Initial layout: z=15
  - Final layout: z=15

$$z = \sum_{i=1}^{m} \sum_{j=i+1}^{m} f_{ij} x_{ij}$$

- **Normalized adjacency score (efficiency rating)**
  - Initial layout: z=15/24=0.63
  - Final layout: z=15/24=0.63

$$z = \frac{\sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} x_{ij}}{\sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij}}$$

- Both layouts have the same adjacency-based scores
- If evaluated based on the total costs (distance-based scores), the results are different:
  - $C_{Initial}$=61,062,70
  - C_{Final}=58,133.34

BLOCPLAN

REL-DIST score

- BLOCPLAN calculates:
  - Adjacency-based score (relationship chart)
  - Distance-based score (flow-between chart)
  - **REL-DIST score** (numerical relationship chart)
    - Distance-based layout cost that uses **numerical closeness ratings** r_{ij} instead of the flow values

$$z = \sum_{i=1}^{m} \sum_{j=i+1}^{m} r_{ij} c_{ij} d_{ij}$$

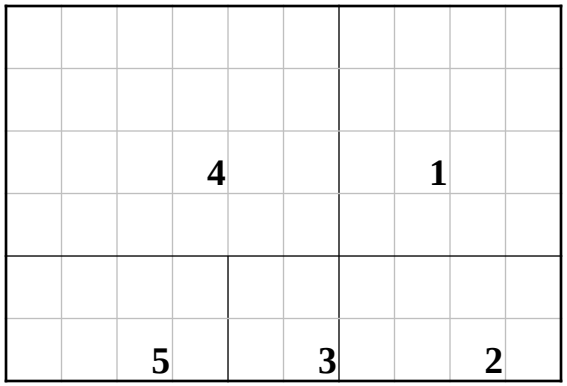
    - Very useful if From-to chart is not available

BLOCPLAN
REL-DIST score – Example 2

- Following Relationship chart and layout are given. Suppose that the following scoring vector is used: A=10, E=5, I=2, O=1, U=0 and X=-10, and compute efficiency rating and REL-DIST score.

	D1	D2	D3	D4	D5
D1		A	U	E	U
D2			U	I	I
D3				U	I
D4					A
D5					

Relationship chart



Proposed layout

BLOCPLAN

A=10, E=5, I=2, O=1, U=0 and X=-10

REL-DIST score – Example 2

$$z = \frac{\sum_{i=1}^{m}\sum_{j=1}^{m} f_{ij}x_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{m} f_{ij}}$$

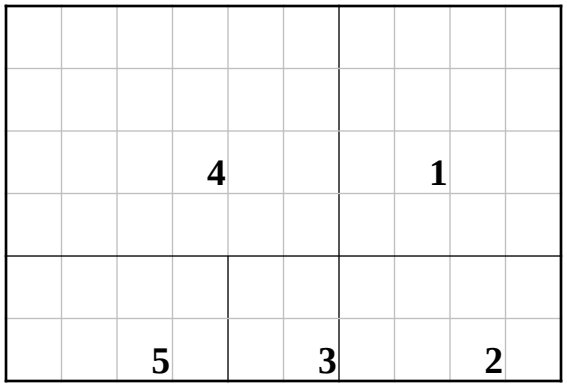
- Efficiency rating

$$z = \frac{A+E+I+A}{A+E+I+I+I+A}$$

$$z = \frac{10+5+2+10}{10+5+2+2+2+10} = \frac{27}{31} = 0.87$$

	D1	D2	D3	D4	D5
D1		A	U	E	U
D2			U	I	I
D3				U	I
D4					A
D5					

Relationship chart



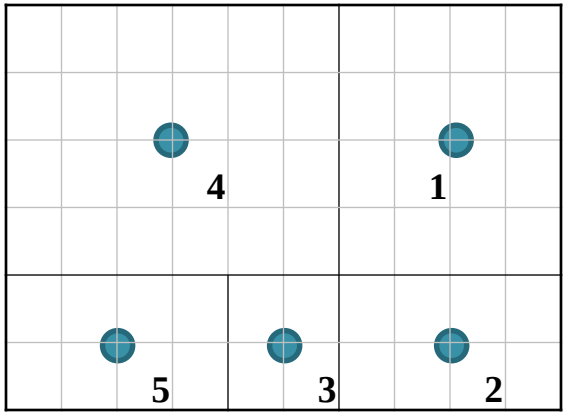
Proposed layout

BLOCPLAN

A=10, E=5, I=2, O=1, U=0 and X=-10

REL-DIST score – Example 2

- REL-DIST score
  - 1. Calculate distance matrix
    - Find centroids
    - Determine the distances between the centroids



Proposed layout

	1	2	3	4	5
1	-	3	6	5	9
2		-	3	8	6
3			-	5	3
4				-	4
5					-

Distance matrix

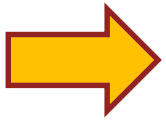
REL-DIST score

A=10, E=5, I=2, O=1, U=0 and X=-10

- 2. Create numerical relationship chart

	D1	D2	D3	D4	D5
D1		A	U	E	U
D2			U	I	I
D3				U	I
D4					A
D5					

Relationship chart



	D1	D2	D3	D4	D5
D1		10	0	5	0
D2			0	2	2
D3				0	2
D4					10
D5					

Numerical relationship chart

- 3. Calculate the total cost

	1	2	3	4	5
1	-	3	6	5	9
2		-	3	8	6
3			-	5	3
4				-	4
5					-

Distance matrix

	D1	D2	D3	D4	D5
D1		30	0	25	0
D2			0	16	12
D3				0	6
D4					40
D5					

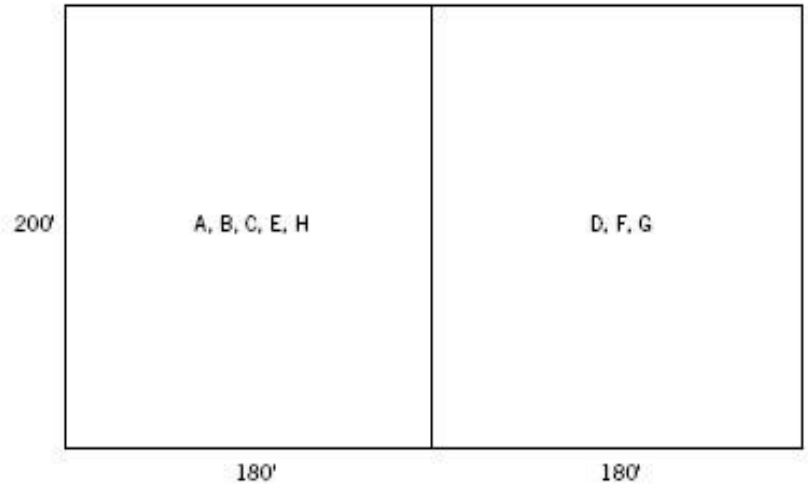
Total cost matrix

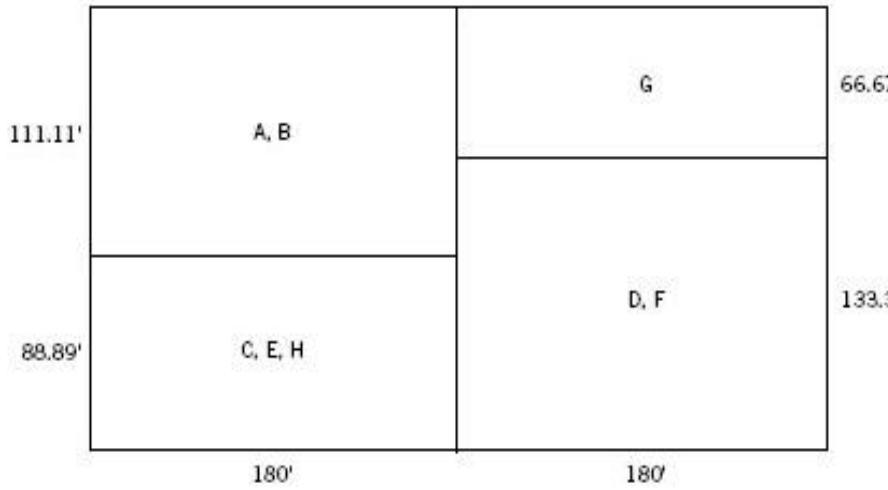
$$z = \sum_{i=1}^{m} \sum_{j=i+1}^{m} r_{ij} c_{ij} d_{ij} = 30 + 25 + 16 + 12 + 6 + 40 = 129$$

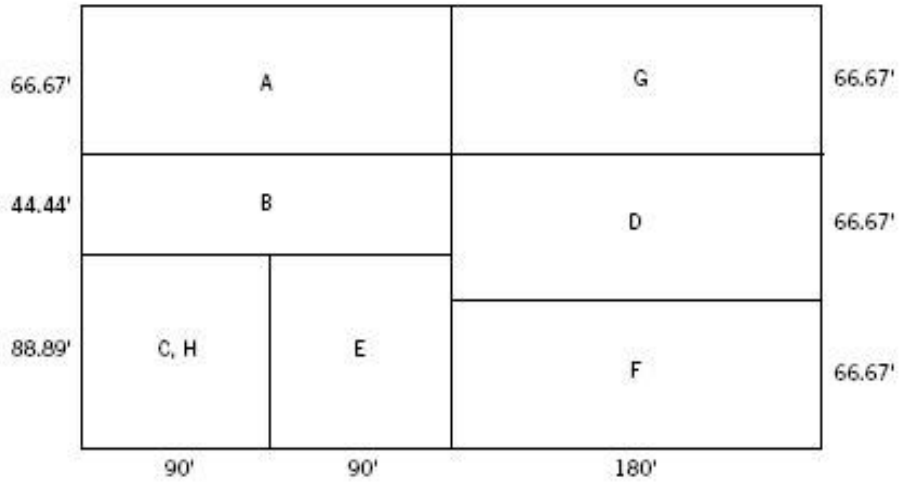
LOGIC – Layout Optimization with Guillotine Induced Cuts

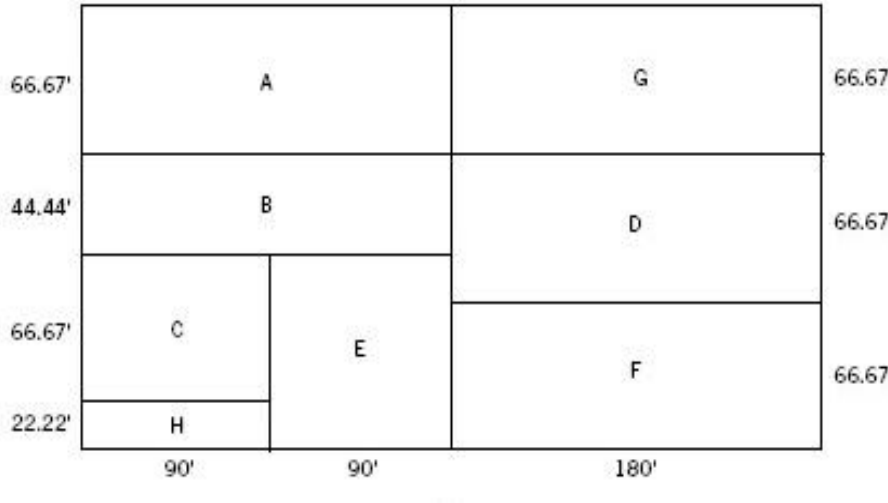
- A series of horizontal and vertical cuts that slice the area to divide the building into departments
- Distance-based objective function
- Continuous representation
- Both construction and improvement algorithm

LOGIC – Construction algorithm

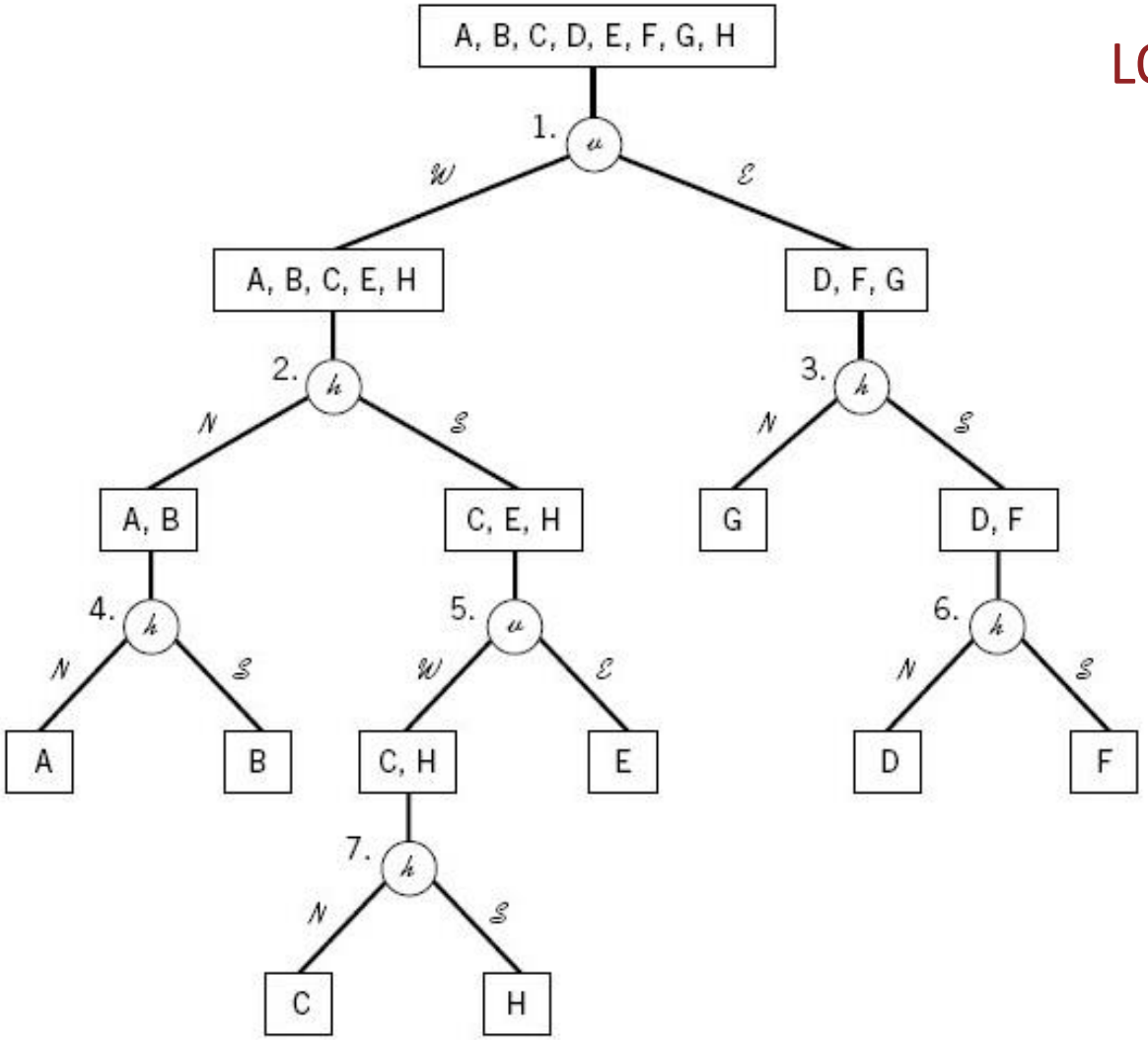








LOGIC – Construction algorithm



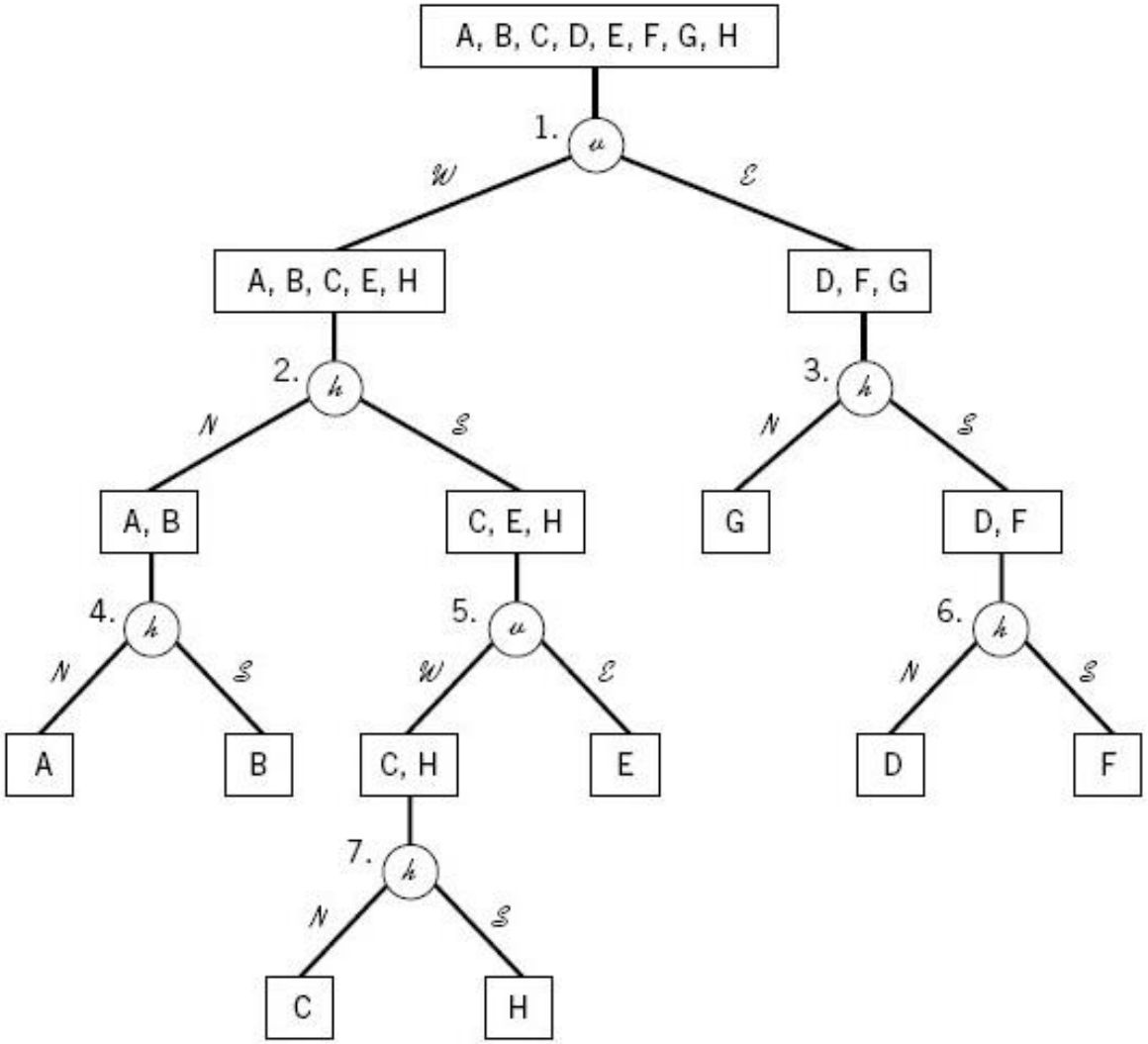
LOGIC Cut-tree

LOGIC – Improvement algorithm

- Exchanging the departments while the cut-tree (structure) remains the same
- Procedure:
  - Swap the two departments in the tree
  - Modify the tree to accommodate the change
  - Perform the cutting procedure based on the new tree

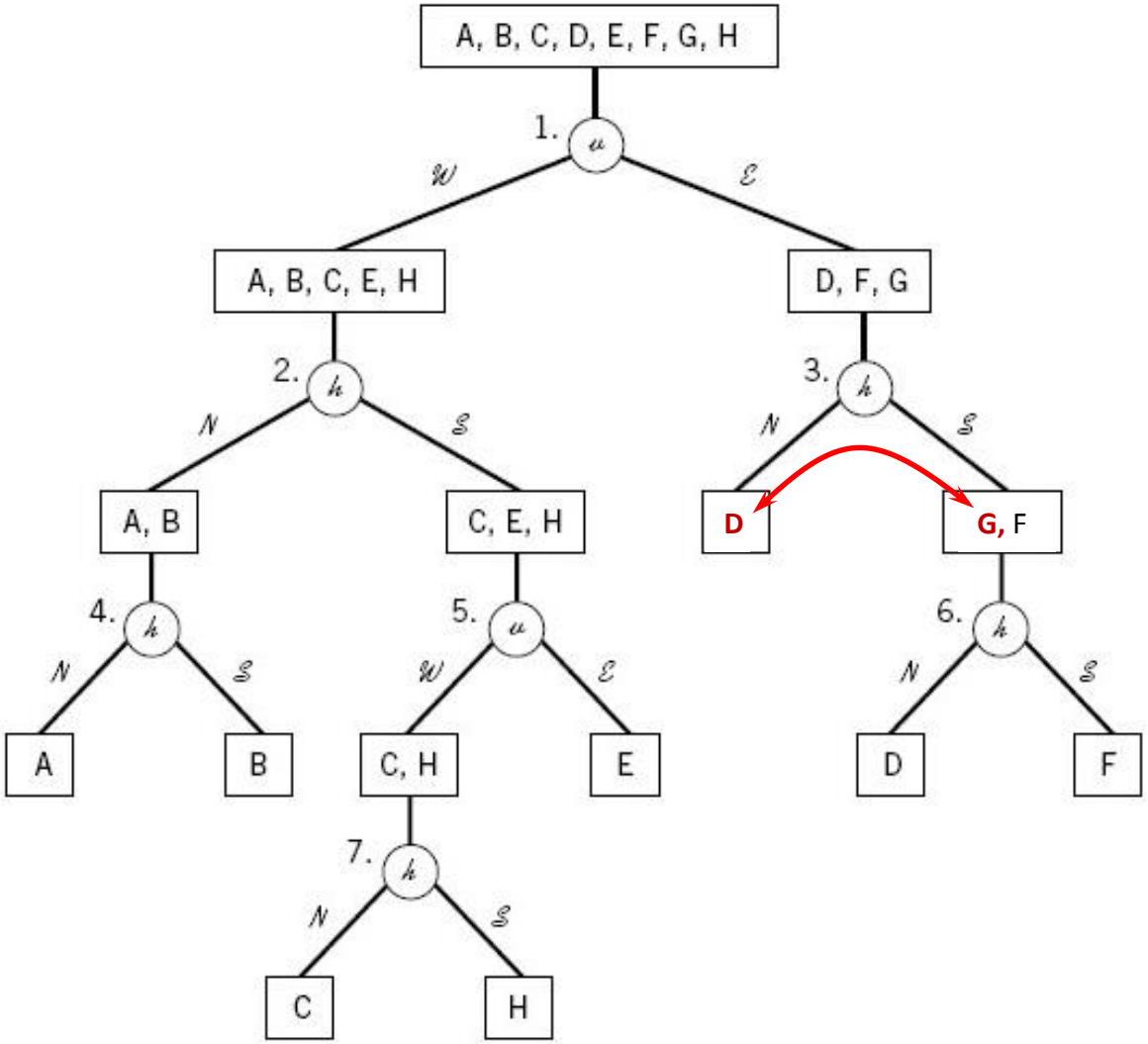
LOGIC – Improvement algorithm

Example 1: Original cut-tree. Now we should swap D &G



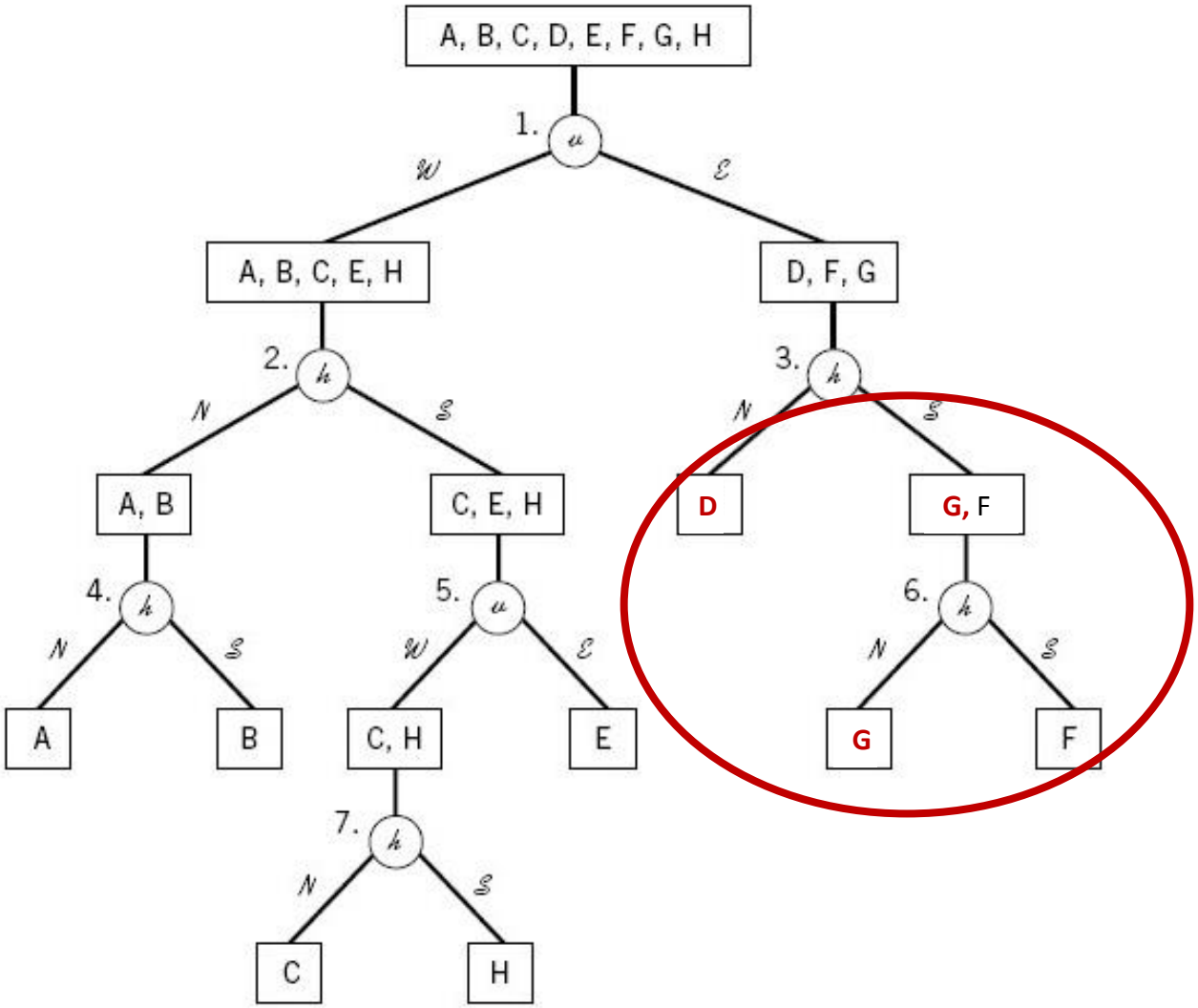
LOGIC – Improvement algorithm

Example 1: Exchange **D** and **G** in the tree



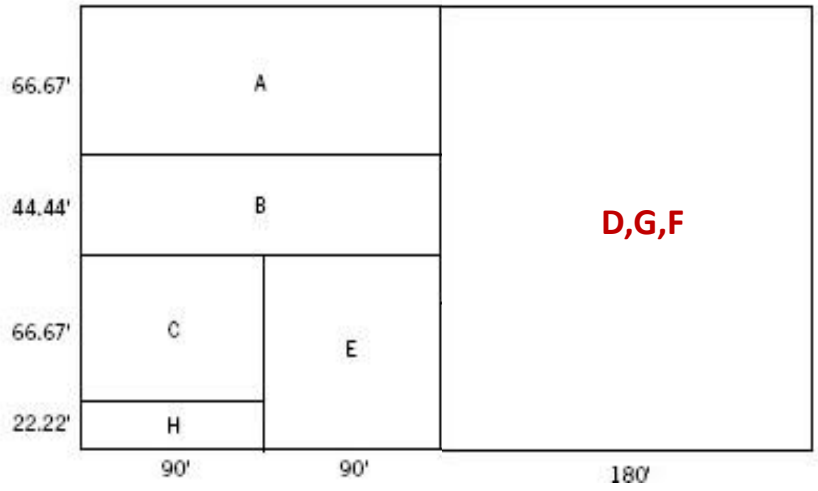
LOGIC – Improvement algorithm

Example 1: Modify the tree to accommodate the change

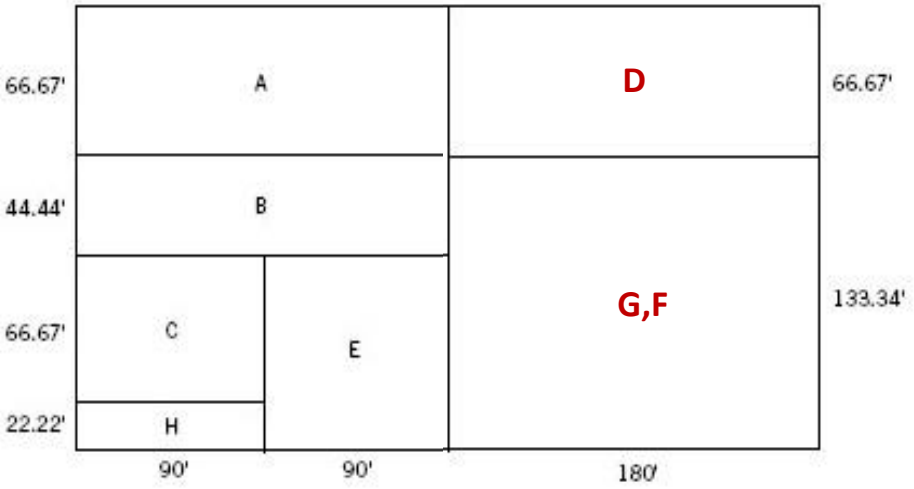


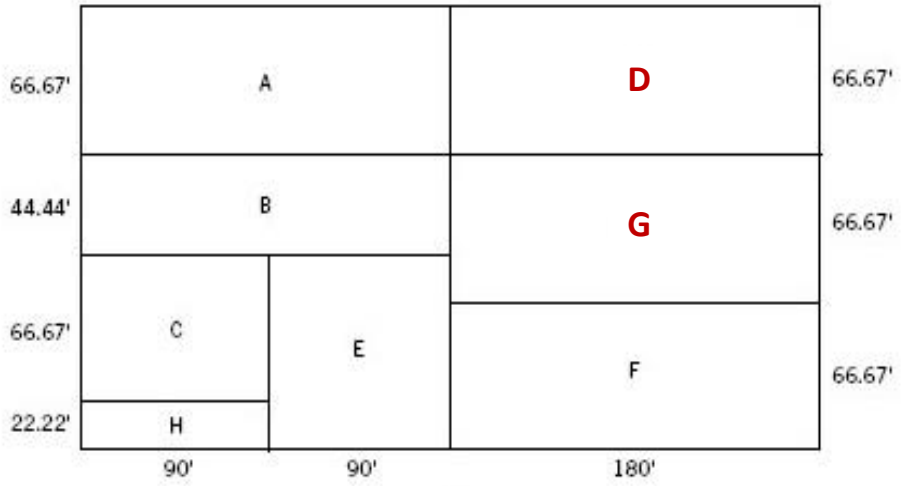
LOGIC – Improvement algorithm

Example 1: Perform the cutting procedure based on the new tree



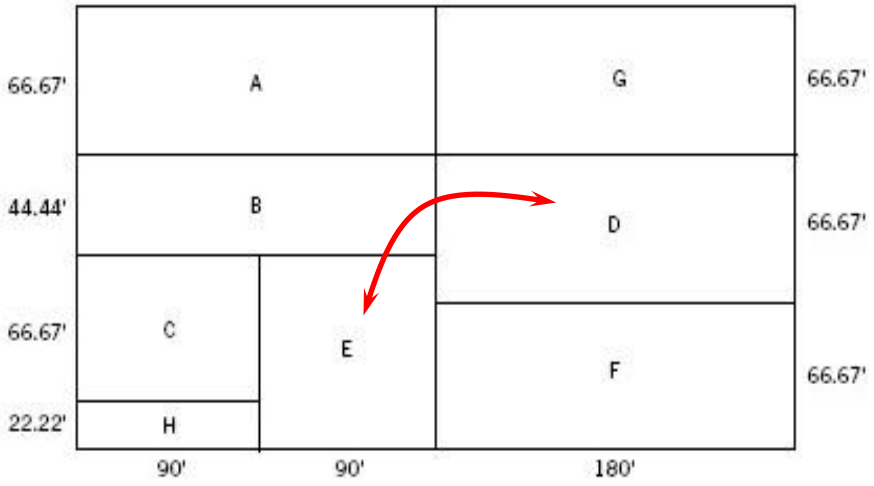
Left part of the layout (A,B,C,E,H) remains the same, the cutting procedure is performed only on the right side (D,F,G)





LOGIC – Improvement algorithm

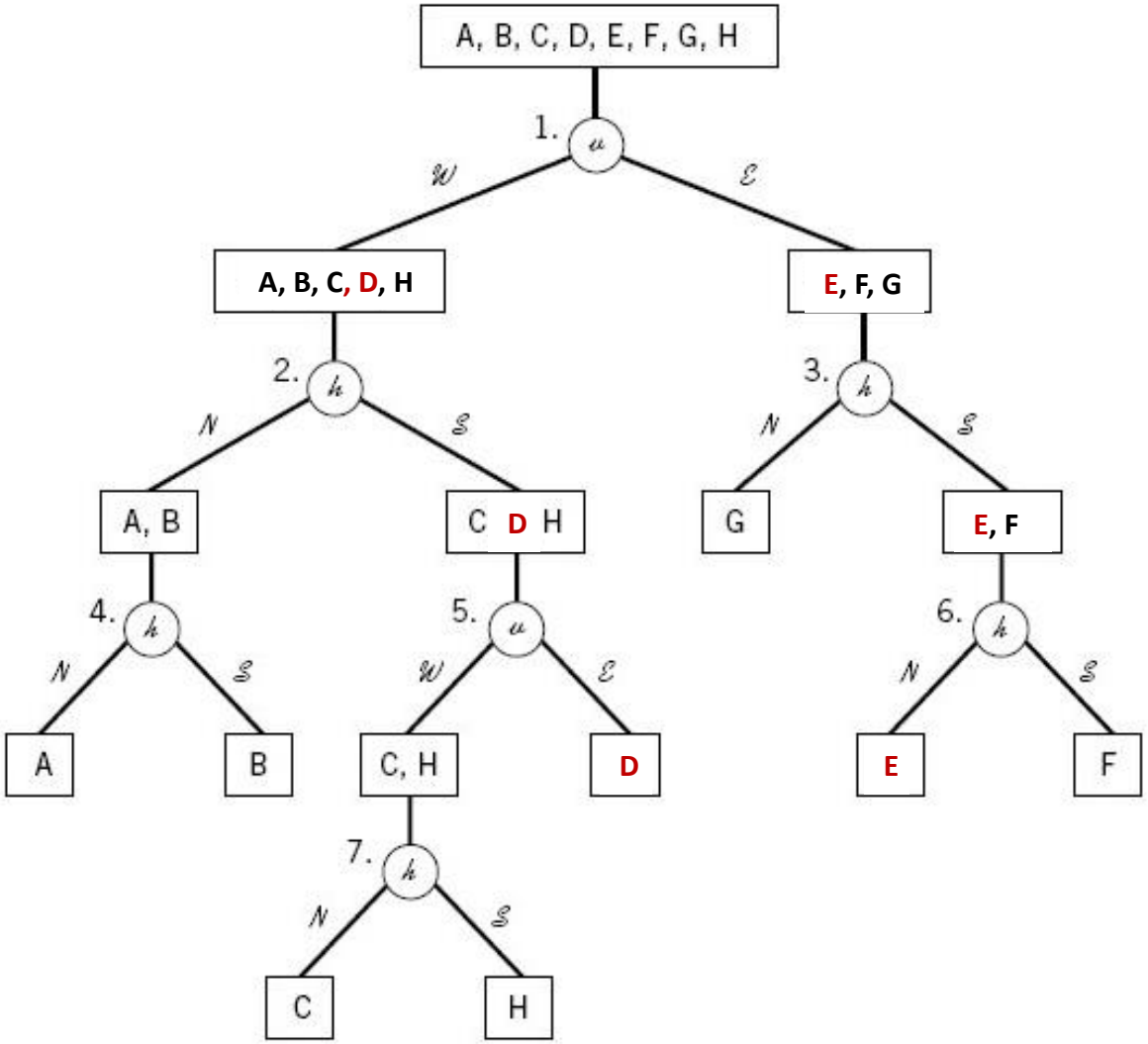
- This procedure allows exchanging the departments of unequal sizes
  - Example 2: Exchange D and E



Original layout

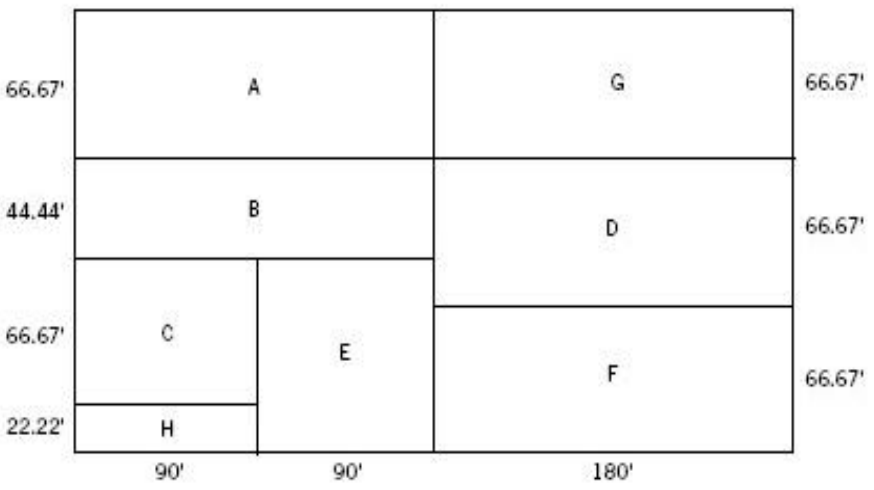
LOGIC – Improvement algorithm

Example 2: Modified cut-tree for the exchange of D and E

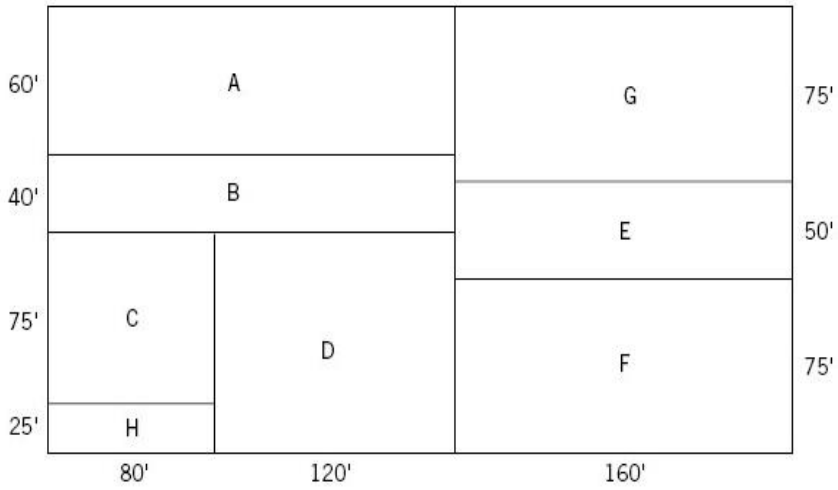


LOGIC – Improvement algorithm

- Example 2: Apply the cutting procedure based on the new cut-tree



Original layout



Final layout

LOGIC - Comments

- Not effective in tackling:
  - Fixed departments
  - Prescribed shapes
- If the building is rectangular LOGIC generates only rectangular departments
- Could be applied to non-rectangular buildings
- Supersedes BLOCPLAN, because all BLOCPLAN layouts are LOGIC layouts (BLOCPLAN's solution space is a subset of LOGIC's solution space)

Next lecture

- Layout generation
  - MULTIPLE
  - CORELAP
  - ALDEP
  - MIP