Analysis of space layout using Attraction Force Model and Quadratic Assignment Problem

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Abstract. This paper researches the usefulness of computerized space layout programs in an actual problem of space layout of more than 50 design units of unequal sizes. This was tested with two existing space layout optimization methods, Quadratic Assignment Problem (QAP) and Attraction Force Model (AFM) as well as a satisficing method, intuitive approach. Necessary inputs for the evaluation processes, the evaluation processes and the resulting space layouts were analyzed for each approach by one designer. Their performance in the design process was criticizedon subjects like preparation of inputs, situations related with multiple trials, evaluation of the resulting space layouts based on given inputs and what those space layouts represented.Generating alternatives is an advantage of computerized space layout approaches so that conditioning on the resulting space layouts decreases in the process but more research has to be done for their practicality in terms of input preparation, evaluation and transfer of outputs.Possible improvements were suggested to increase their usefulness in the professional field.

Keywords:computerized space layout approaches, quadratic assignment problem, equilibrium method, intuitive approach

1 Introduction

Space layout is a complex architectural problem because of the interdependent structure of individual design objects and the vast number of solutions even with small sized problems. Researchers have been approaching to this complex problem with different methods for almost 60 years (Koopmans, Beckman, 1957).

The initial critics on the performance of the computerized space layout approaches were published in around 1975 (Scriabin, Vergin, 1975). The recent publications in the literature are based on the weak interest of companies and architects to computerized space layout approaches. This research was done to contribute in the literature by exposing the performance of the computerized space layout approaches in an actual design process and seek for the possible reasons of the disinterest of the architects in them.

Different programs were developed for the problem of space layout using different approaches both in commercial or academic use (Canen, Williamson, 1998). The

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search for the model used in the design process was based on its capability to handle space layout problems greater than 50 design units of unequal sizes. Additional requested criteria were to optimize adjacency relations, to work in 2D, to be available and to be user-friendly. In this regard, two models, QAP and AFM were selected because of their basic representations, ability to deal with large size problems and availability.

QAP is formulated as the assignment of facilities to cells of a grid to minimize the transportation costs (Koopmans, Beckman, 1957). For the QAP applications, CRAFT procedure was used in Facility Layout®[1] program. Computerized Relative Allocation of Facilities Technique, CRAFT, was formulated in 1963 to increase the efficiency of a manufacturing plant, speed up the evaluation process and to generate more alternatives to the space layout problem (Buffa, Armour, Vollmann, 1964).Facility Layout® is a program; which uses CRAFT in space layout organization. The program uses improvement approach, which decreases the total cost of an initial layout by doing pair-wise switches during the optimization. Design units of unequal sizes are subdivided into standard modules. The program operates in Microsoft Office Excel®[2](Jensen, 2004).

AFM is an equilibrium method application and Kangaroo Physics[3] program was used for this model's construction.Equilibrium method is the application of Newton's second law of motion on the design objects in the space layout to reach an intended design state.Kangaroo Physics is an add-on of a3D Modeling Program, which interactively simulates physical rules in a 3D environment and gives the user to chance to interact with the behavior during the simulation(Piker).

The designer also used intuitive approach in the process next to computerized space layout approaches. Intuitive approach uses satisficing instead of trying to find the optimum result as in the cases of the computerized space layout approaches.

There are various advantages and disadvantages of the different approaches, such as representing various architectural information of intuitive approach, practicality of AFM and alternative space layout optimizations with same given input of QAP. Intersecting forces and the absence of a resulting space layout evaluation mechanism of AFM and extensive input preparation and transfer of input of QAP can be mentioned as disadvantages of those approaches. Representations of the computerized space layout approaches should be evaluated by the designer and has to be improved for the further design process. Considering those experiences, the ways to increase the usefulness of computational space layout approaches in the professional field will be discussed.

Initially a brief review of the space layout approaches will be mentioned. Principles of QAP and AFM will be explained and similar researches about the usefulness of the computerized space layout approaches in the literature and the use of these approaches in practice will be presented. Following that the methodology of the research will be explained for three different approaches in detail.Lastly results of the

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[3] by Daniel Piker

applications with these approaches will be given and the conclusions on this research and recommendations for future work will be mentioned.

2 Space Layout Approaches

Space layout approaches usually contain both representational approaches and evaluation methods. The comparison of the space layout approaches used in this research based on those representational and evaluation differences and their possible effects on the design process required a particular classification as such, not specifically mentioned in the literature.

Representation approaches areways of abstractingthe topological relations in and/or geometric features of the space layout for analysis and synthesis of space layouts (Baykan, 2010). Those approaches could be classified as graphs / wall representations and constraint based approaches like region connection calculus and rectangle algebra (Baykan, 2010). Shape grammars are also used for describing, analyzing and synthesizing the space layouts. Next to these methods, other basic representations also exist like, grid representations of QAP model and point representations in space of AFM.

Evaluation methods are ways ofanalyzing the space layout based on designer's criteria and altering it with different methods. Those methods could be classified as satisficing and optimization methods. Finding an acceptable or good enough solution to a design problem where best solutions are unknowable is called satisficing(Simon, 1981). Selection of good enough solutions doesn't mean that the designer is satisfied with less but he has no other choice. The designer used only satisficing method during the intuitive approach in the design process.The technique of finding the best result or possibly best results of a design problem according to specified necessities is called optimization (Arvin, 2004). QAP and AFM use optimization method.However during the applications of the computerized models designer also used satisficing method for their evaluations.

A review of space layoutapproaches and programs developed for these approaches can be found in the article of Singh and Sharma (2006).

2.1 QAP

Koopmans and Beckman (1957) formulated the problem of locating facilities and activities in space as the QAP. QAP is formulated as the assignment of facilities to cells of a grid to minimize the transportation costs. The method was developed for the benefit of companies in terms of cost minimization literally however cost also defines the weight of relations between design units. The further use of the term could be understood as such.

Fixed cost term and interactive cost term is calculated in the QAP formulation and gives a total cost. QAP tries to find an suitable arrangement to decrease the amount of total costs. Fixed cost is dependent on the assignment of a design unit to a particular site and is independent from the interactions with other design units whereas interactive cost term calculates material transportation flow costs and design units are interdependent (Liggett, 2000). The formulation is as below (Kay, 2009):

Given,	M=design units	M ≤ N=sites	(Kay, 2009)
	M ={i,j….}	N={k,l….}	

Minimize TC (Total Cost)
$= \sum_{i=1}^{M}.\sum_{k=1}^{N} cik.xik \quad + \sum_{i=1}^{M}.\sum_{k=1}^{N}.\sum_{j=1}^{M}.\sum_{l=1}^{N} cijkl.xik.xjl$

subject to

$\sum_{i=1}^{M} xik$=1, for all sites k = 1,...,N
$\sum_{k=1}^{N} xik$=1, for all design units i= 1,...,M
xik = { 0,1 }
where
xik = {1, if design unit i is assigned to site k,
0, otherwise
cik = fixed cost of assigning design unit i to site k
cijkl= cost of assigning design unit i to site k when design unit j is assigned to site l

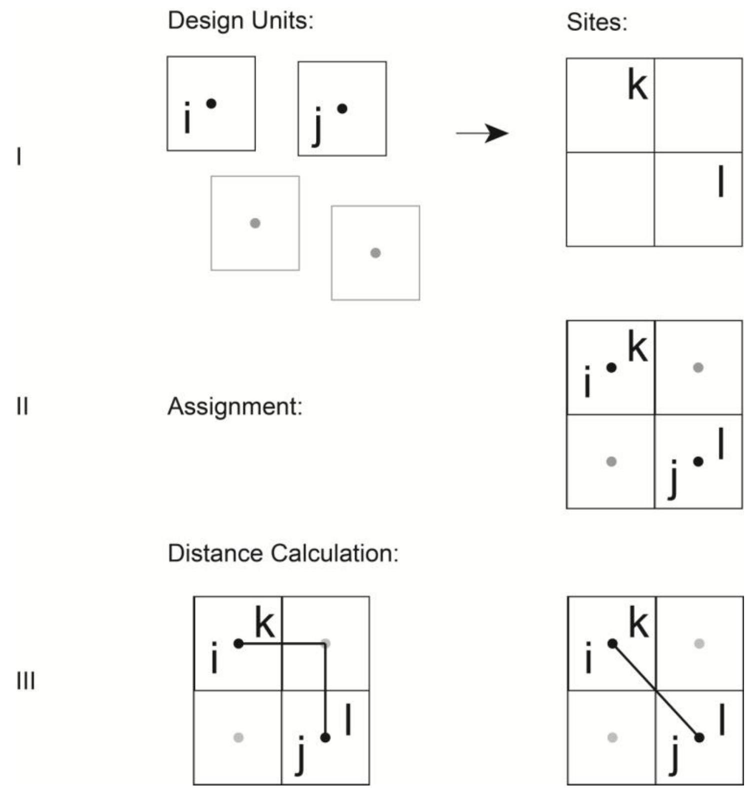

Fig. 1.A basic illustration of an assignment. Drawn by the author.
I-M number of design units will be assigned to N number of sites
II-A possible assignment
III-Distance calculation methods, rectilinear distance on the left and euclidian distance on the right

Let's assume that, M number of design units will be assigned on N number of sites as in Figure 1-I. A possible assignment is shown in Figure 1-II, where design unit i was assigned to site k and design unit j was assigned to site l. The assignment of any design unit on any site has a cost, so this cost will be calculated as fixed cost term. For instance, in the formulation above xik value will be 1 according to this assignment. Then fixed cost of assigning design unit i to site k, cik will be valid and calculated in the formulation.[4]

Secondly the interactive cost term will be calculated between design unit i and design unit j. The values of xik and xjl will be 1. Then cost of assigning design unit i to site k when design unit j is assigned to site l, cijkl will be valid and calculated. The value cijkl is calculated by (cijfij)dij, which is the multiplication of the material

[4] Not every QAP program calculates fixed costs, like the one used in this thesis, Facility Layout®.

transportation flow cost(cost matrix. flow matrix) and distance. Material transportation cost and material transportation flow matrixes were both defined by the designer as an input before the optimization. Distance can be calculated either by taking the rectilinear distance or euclidian distance between the centroids of design units i and j as shown in Figure 1-III during the optimization. Total cost (TC) of the space layout is obtained by this method.

The illustration; shown in Figure 1. has 4 design units and 4 sites. The number of all possible assignments for this problem can be calculated by M!, which is 4!=4.3.2= 24. However realistic space layout problems usually contain more than 15 design units, which makes it hard for QAP to consider all possible assignments because of vast numbers of solutions (Liggett, 2000) and extremely long computation time (Armour, Buffa, 1963).

Since QAP isn't able to evaluate all possible assignments of realistic design problems, optimum result is harder to find. Based on this, researchers developed procedures to find the optimum solution; which are constructive and improvement procedures.

Constructive procedure places the most strongly related design unit in the center of the layout and continues until no design units left while the total cost is being minimized.

Improvement procedure makes pair-wise switches between the design units to decrease the total cost. In pair-wise switching, two design units exchange their sites and the new cost is calculated according to this new organization.A widely used algorithm of this procedure is CRAFT.CRAFT makes pair-wise switches between either adjacent design units or design units of equal sizes[5] (Armour, Buffa, 1963).

Applications of CRAFT for buildings of different functions are exemplified in Buffa, Armour and Vollmann's article (1964). It is possible to fix design units at desired sites by the designer's request. The maximum capacity of CRAFT program was 40 design units, when it was first formulated. To deal with larger sized problems different kinds of procedures were developed under improvement procedure, like, simulated annealing (Jojodia, Minis, Harhalakis, Proth, 1992)and genetic algorithms (Jo, Gero, 1998); however they mostly end up with suboptimal results.

QAP is applied with Traditional CRAFT method in Facility Layout® program; which operates in Microsoft Office Excel®[6] (Jensen, 2004).

2.2 Equilibrium Method

Newton's second law of motion states that, to change the design object's velocity and position, a force should be applied on it. Equilibrium method can be defined as the application of Newton's second law of motion on the design objects in the space layout to reach an intended design state to satisfy various topological or geometric

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[5] Design units of unequal sizes can also be switched; but separations more likely to occur between the modules of the same design unit.

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design criteria. Arvin and House (2002) states that any design criteria which are related with the position of any design object in the space layout can be translated into forces as shown in Figure 2., where a designer's problem is translated into a dynamics problem.

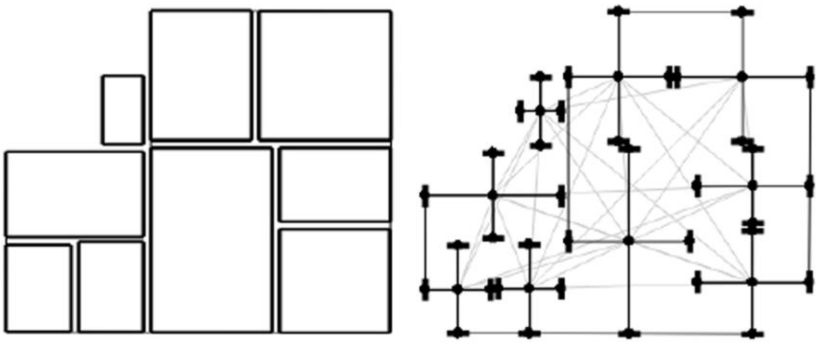

Fig. 2. Translation of the designer's problem on the left to a dynamic problem on the right. Arvin, 2004.

The lines on the left image represent the bounding walls of the design units, where on the right side, points represent the design unit centers, black lines represent extensions from the centers to the bounding wallsand the light grey lines represent the forces to be applied to satisfy the design objectives between those design units.

Topological criteria regulate how one design unit relates to another, like adjacency, separation, orientation, etc. are applied on the center of the design units; geometric criteria regulate the design unit boundaries, area and shape, like alignment, offset, area, proportion, etc. are applied on the edges of the design units (Arvin, House, 2002).

Circular geometries are used to satisfy the topological criteria, to maintain the design units to slide over each other, without preventing each other during the displacement. However after the topological criteria are completed, Arvin and House (2002) recommends to transform the circular geometries into rectangular geometries during the implementation of geometric criteria, to evaluate the design unit's shapes and the boundary relations with each other.

An important concept of the equilibrium methodis shown below in the Figure 3.

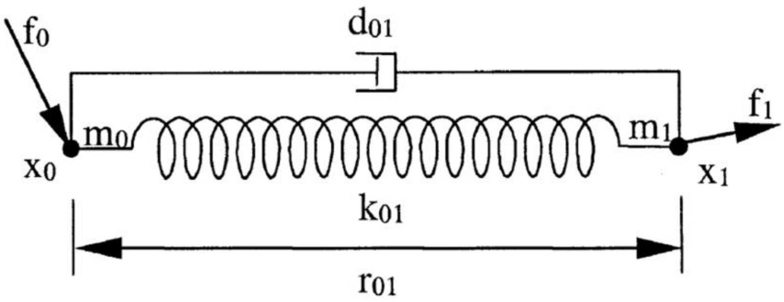

Fig. 3. Simple mass-spring-damper system. Arvin, House, 2002.

In Figure 3. m0 and m1 represent two points. A spring connects the two points with spring constant, k01and current spring length is l01 is the magnitude of the vector between positions x0 and x1 at the current time. Desired rest length between the design units is r01. Dashpot has a damping constant of d01.

Spring uses the f0 and f1 forces, with a magnitude proportional to l01- r01. The direction of the force will be along the line connecting the two masses. The spring applies a force to bring the masses together or apart, when they move further or closer to each other respectively. The parallel attached dashpot damps the motion of the masses by producing forces proportional with damping constant, d01 to their relative velocity towards or away from each other, thus reducing the kinetic energy introduced by the spring forces (Arvin, House, 2002).

Equilibrium Method is applied with AFM[7]. AFM was constructed in Kangaroo Physics add-on (Mulders, 2012) with necessary components to organize separate masses, in this case design units, by physical forces according to adjacency relations.Kangaroo Physics add-on, which interactively simulates physical rules in a 3D environment and gives the user to chance to interact with the behavior during the simulation (Piker). The program operates in in Grasshopper®[89].

2.3 Use of Computerized Space Layout Approaches in Practice

Performance of computerized space layout programs was an interest of the space layout researchers. After the presentation of QAP program CRAFT in 1963 by Armour and Buffa, Scriabin and Vergin (1975) published an experiment based on the comparison of humans and computers for the efficient solution of the problem of space layout. This publication initiated discussions (Buffa, 1976) (Scriabin, Vergin, 1976)and differently structured experiments were published to analyze the performance of the programs, which concluded in favor of humans or computers as in

[7] The program can be found in Mulders, 2012 (I).

[8] Grasshopper® is the 'explicit history' plug-in of Rhinoceros® 3D Modeling Program.

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Coleman’s (1977), Lewis and Block’s (1980) and Trybus and Hopkins’s (1980) works.

Baykan (1995) presents an evaluation of QAP by interviewing two designers in different companies. Both designers use the program in the block plan design phase, by input preparations and optimizing multiple initial configurations. Despite advantages like dealing with complexity and increasing the confidence of the designer on the layout, the software used have difficulties like extensive input preparation and transfer of output to other sketching programs.

Another research by Canen and Williamson (1998) seeks the use of computerized space layout approaches by the companies and their contribution in the competitive purposes. The research showed that academic research is not really known by companies and doesn’t reflect on their practice and the companies are not interested in academic research either and deal with the problem by their own methods.

Lobos and Donath (2010) state that 50 years of research shows that none of the computational solution methods are practically used or accepted by the architects and relate this with both space layout researchers and architects the lack of interest in each other’s fields in approaching the problem.

3 Methodology

The process was initiated by the definition of the design program of a creative facility, composed of 69 design units. 56 of 69 design units are together in a core, composed of four functional zones, and additional 13 design units are separately distributed on the site.

After defining the qualities of the design units and their possible desired relations, the space layout problem was complex enough to solve manually due to vast number of design units.Therefore performance of three different approaches for the solution of this problem was researched.

The operations were done and evaluated by one designer, who is the author of this research.Three space layouts were obtained from the three different approaches and necessary inputs for the evaluation processes, the evaluation processes and the resulting space layouts were analyzed. The space layouts were analyzed based on both the satisfaction of the given input and what they represent.

3.1 Analysis with AFM

Design goal of AFM research is to achieve a space layout, which produce a configuration of the design units based on desired adjacencies.For AFM applications the requirements are; list of design units, sizes of design units and the related design units or adjacency relation inputs. 58 adjacency relation inputs were prepared intuitively between 69 design units of unequal sizes including identical design units for this research.A lower limit was not defined in the beginning, but almost 50 out of 58 adjacency relations was expected to be satisfied in the resulting space layout.

Various intuitive reasoning between the design units was expressed in the same way as an ‘adjacency relation’. The reasoning is based on conditions like, having identical function, belonging to same functional zone, being functionally complementary, being visually related, having service requirements (Demir, 2014).Only the related design units have to be mentioned as an input, so the number of input depends on the designer’s objectives. AFM also doesn’t require quantity of adjacency relation. These two features of AFM speed up the input preparation phase and prevent additional complexity for the designer because a relation can be defined whenever it is thought as important.

The space layout initially consists of randomly distributed design units in circular geometries with names written on without any space layout boundary. The configuration only depends on the order of design units in the list, so it is not possible to initiate the optimization process with an initial space layout configuration.

During the optimization related design unit names were transferred into strings and theirs centroids were connected the by a component, which attracted them to each other, therefore all of the design units displaced according to 58 adjacency relation inputs with initial adjustments of AFM. After the state of equilibrium a space layout was obtained. Designer evaluated the layout visually by comparing some of the relations in the layout with the given inputand saw that most of the relations were not satisfied andadjusted features like damping or stiffness in the spring component or strength of the power law forceof AFM. First space layout was obtained withmodified adjustments of AFM after multiple trials with the satisfaction of the majority of the relations, which is 53 out of 58 relations as shown in Figure 4.

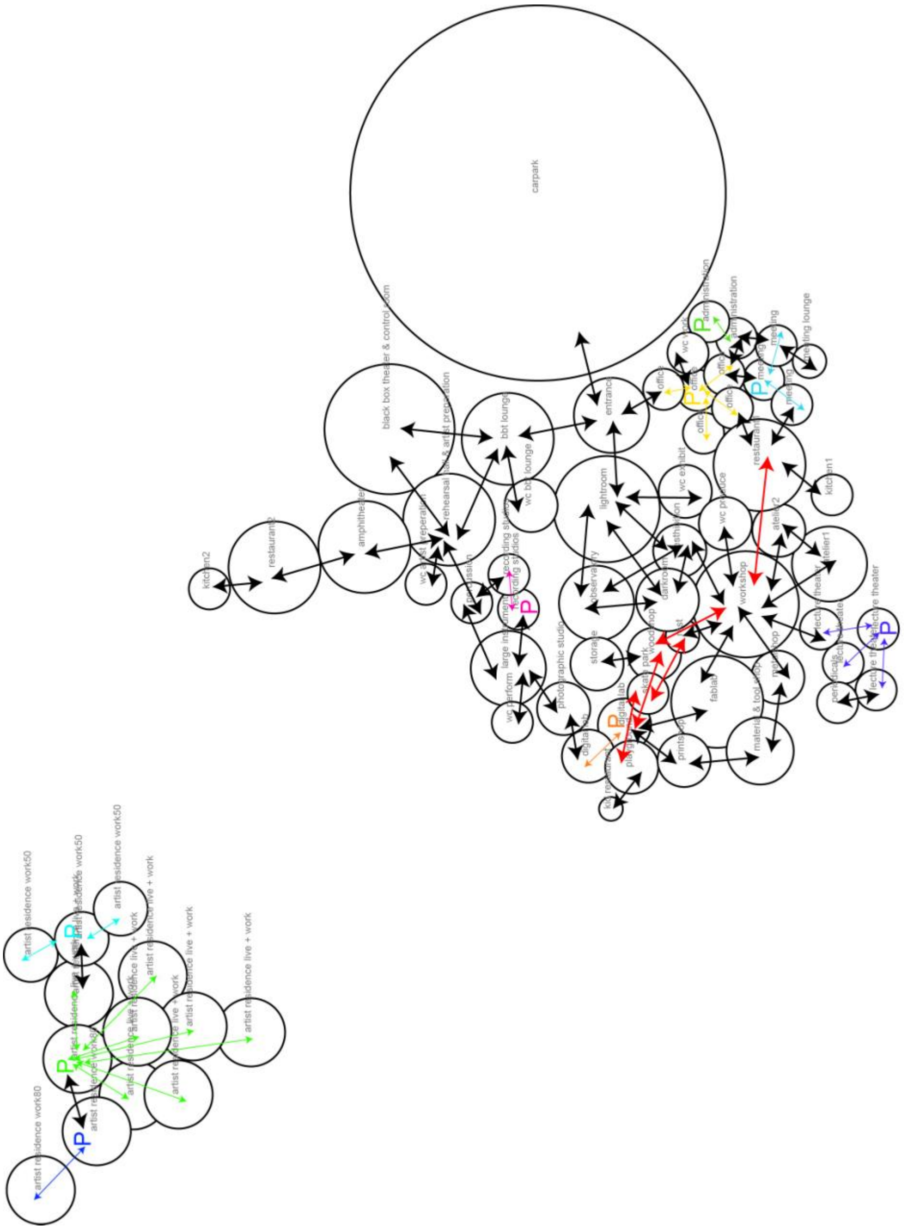


Fig. 4. Relation satisfactions of space layout of AFM. P indicates the parent design unit. The little colorful arrows show the attraction of identical design units to the parent design unit. Big black arrows indicate satisfied relations. Big red arrows indicate not satisfied relations. Drawn by the author.

3.2 Analysis with Intuitive Approach

Design goal of intuitive approach research, is to develop the space layout according to various criteria. The analysis process is more designer oriented and unique and without any dependence on a computerized space layout approach.
For intuitive approach, the designer identifies which kinds of inputs are required. In this work input about which design units are public or private, which design unit belongs to which zone, which design units should be secluded; height, sound isolation, light / dark design units were prepared intuitively (Demir, 2014). Inputs on the site and environmental conditions, like site elevations, sun path, wind directions, were also gathered from external sources (Demir, 2014).Neither of those inputs were used in the other models.
During satisficing process the designer applied those input one by one on the layout obtained from AFM applications. Those steps developed the initial space layout and formed a new one as shown in Figure 5.

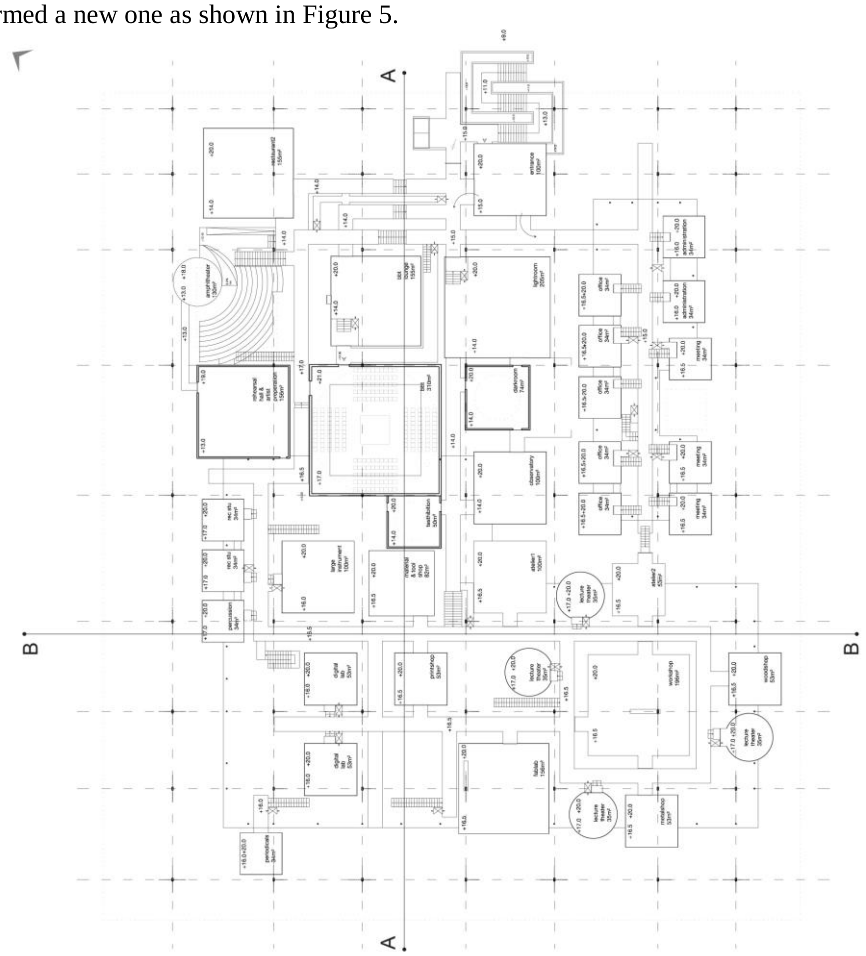


Fig. 5. Space layout of intuitive approach. Drawn by the author.

3.3 Analysis with QAP

Design goals of QAP research is to observe the optimization performance of the model by initiating the process with various space layouts including a random space layout generated by Facility Layout® and the space layout of the intuitive approach.Those space layouts include a random layout, a random layout with 4 design units fixed on the desired zones, a random layout with 10 units fixed on the desired zones, space layout of intuitive approach and space layout of intuitive approach with identical units adjacently placed[10].The reason of adding space layouts with fixed design units in the research is to analyze the relations both between the design units and between the design units and the site during the optimization process.

For QAP applications the requirements are; list of design units, sizes of the design units, flow matrix of the design units, material handling cost matrix of the design units, and the size of the proposed space layout in length and width.

For the assignment of flow matrix inputs between the design units, sensitivity analyses were done using different flow input sets (Demir, 2014). After the sensitivity analysis, selected input values were assigned between the design units depending on the strength of their relationship.1431 flow inputs were given to the flow matrix for 54 design units in the core of the design, of unequal sizes, including identical design units(54*(54-1)/2= 1431). These inputs were coherent with the adjacency relation inputs from the previous AFM applications.Material handling cost matrix inputs were taken as 1 for each relation; to avoid additional complexity when multiplied with the flow matrix (Demir, 2014).

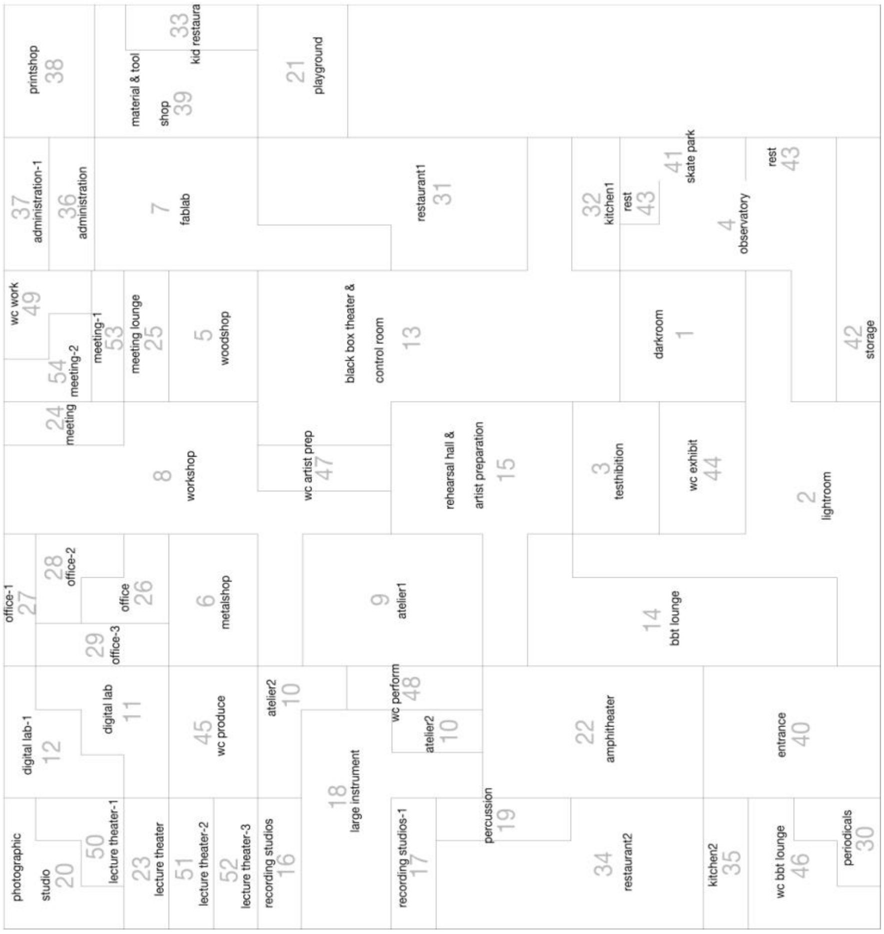
Interdepartmental flow is mostly used for materials, but in buildings of different functions, it can be used for other criteria like people flow, etc. (Buffa, Armour, Vollmann, 1964). As in the previous processes, different reasonings like being in the same zone, functionally complementary, people and material flow and so forth were expressed in the same way. If the relation was strong, then the highest flow input was given.

Fixed cost inputs are not requested nor calculated by the program. But the designer manually calculated the results of the fixed cost analysis to analyze the relation of the design units with the site. Initially three zones were identified on project site related with main transportation axis and landscape. Modular layout of the Facility Layout® program was translated into the project site. A fixedcost was given for each design unit for each one of the three zones. Fixed cost inputs were given based on the same intuitive reasoning used in the intuitive approach. Lower costs were given to the design units to be placed in a desired zone.

[10] After the use of AFM in the design process, intuitive approach was used to organize the space layout of the design. During the intuitive approach, identical units were placed separately to increase interaction in the core. However identical design units were placed adjacently in the layout mentioned.

A random space layout of Facility Layout®initially consists of sequentially allocated design units in modular geometries with numbers representing the names written on and with a cost. The designer can also initiate the optimization with an initial space layout configuration.

Total costs of the layouts before and after the optimizationswere noted down. Fixed costs[11] and relation satisfactions of the optimized layouts; according to given flow matrices were calculated manually. The layouts were redraftedfrom grids to bounded spaces, where design units exist, and their functionality wasanalyzed in terms of their functionality.One of the optimizations with the least cost was selected as the third space layout as shown in Figure 6.



[11]Facility Layout® doesn't request and calculate the fixed costs, but a manual calculation was done by the designer to analyze the relation of the design units with the site.

Fig. 6. Redraft of space layout of QAP. Drawn by the author.

4 Results

All space layout approaches were useful in the design process to a degree. AFM was basic and practical in preparation of inputs and transfer of the outputs. QAP led to design variations prevents the conditioning on the first result found and allows the designer to initiate the optimization process with a desired space layout configuration. Intuitive approach represents the architectural qualities of thedesign best.

The main disadvantages of the three approaches can be explained as follows. In AFM the intersecting forces, such as spring and power law, decrease each other's efficiency and led to high numbers of unsatisfied relations in the resulting space layout. In this case the designer should adjust the model parameters and do multiple trials to reach to a better result. The model is also not capable of generating an alternative space layout to the given relations in the given order of the design units in Microsoft Office Excel® file with the same adjustments. So the designer may be conditioned on the resulting space layout.Another important finding is that AFM is sensitive to; design unit scales, initial configurations, sizes and number of design units. The designer should be aware that changes in those criteria could alter the resulting space layout.

During the intuitive approach, the designer developed the space layout gradually based on satisficing without seeking for the optimum result. Depending on the designer, generating an alternative space layout in the same detail of representation may be more compelling than the computational space layout approaches.

In QAP mainly the preparation of input is complex and time consuming because the flow matrix requires n*(n-1)/2 flow inputs, which gradually differentiate depending on the strength of the relation between the design units and QAP is sensitive to different gradual flow inputs. The random selection of switching pairs may create a narrow solution space, and end up with weak solutions. Multiple trials are necessary in QAP to have an idea about the limits of the solution space. QAP may generate space layouts with lesser costs than the space layout of the intuitive approach as a result of higher number of switches during the optimizations and with irregular and disconnected design unit boundary shapes at the end as a disadvantage. Another issue of QAP is the transfer of output to other drafting programs.

None of the methods contain a practical method to understand the satisfaction of desired relations, except the space layout cost in QAP. However the cost is not a strict indicator of satisfaction of desired relations because there may be several reasons of a low costlike more switches and irregular design unit shapes or an initial representational layout with low cost or different flow input sets. So the cost evaluation should be supported with additional evaluation methods.

Design criteria are better to be quantifiable during the formulation of the problem so the results can be understood accordingly and well judged (Kalay, 2004). To understand the performance of the program, the highest flow inputs were checked one by one by looking at the relations of the design units on the resulting space layouts. A color was given to each relation according to the final positions of the design units in the space layout as illustrated on the left of Figure 7. However this method is more difficult in QAP than AFM, as the number of input to check increases. Space layouts with low costs have the highest relation satisfactions and layouts with high costs have the least relation satisfactions. Relation satisfactions color schema on the right of Figure 7 shows that, relations with blue color turn to red and claret red colors after the optimizations.

The relations of the design units with the site were checkedby calculatingthe fixed costs during QAP applications manually. It was seen that as the number of the fixed design units increased, fixed cost of the optimized space layout decreased. This is related with the designer's same intuitive reasoning on identifying the flow inputs and fixed cost inputs. Site allocations were mostly taken into consideration during intuitive approach, but not in the applications of AFM.

Resulting space layouts of all approacheshave different representations with varying levels of details as shown in Figure 8. The designer realized that the space layout representations of AFM and QAP don't contain majority of the necessary architectural information, but only carry the information on the given input based on the size of the design units and the adjacency relations. Even if design unit boundary shapes, space layout boundaries and circulations are represented in the space layouts, it is not known if these representations are valid for the design or will be used in the further design process. So the designer should decide if they are coherent with the design criteria or not and design them from the very beginning for the further processes if necessary. For the further design process additional analysis could be done to detail the space layout representations.

Brief notes of the author on the improvement of the models are: In AFM; additions of an evaluation mechanism[12] to understand the satisfaction of desired relations and a component[13] to change the order of the design units in Microsoft Office Excel® file, therefore their initial configurations to end up with space layout alternatives. The modification of the model structure according to gradual adjacency relation inputs is also possible but it may also increase the complexity of this basic model and add difficulties like input preparation in QAP. In QAP, additions of fixed cost calculations to the program to strengthen the relation of the space layout with the site and export options to drafting programs would be useful.

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[12] A component could be added in the model to relate the adjacency relations to the distances between the design units in their final positions.

[13] The initial configuration of the space layout in AFM depends on the order of design units in Microsoft Office Excel®. A number slider can be connected to the random initial distribution component and as it changes, the initial random placement can change quickly and give multiple results.

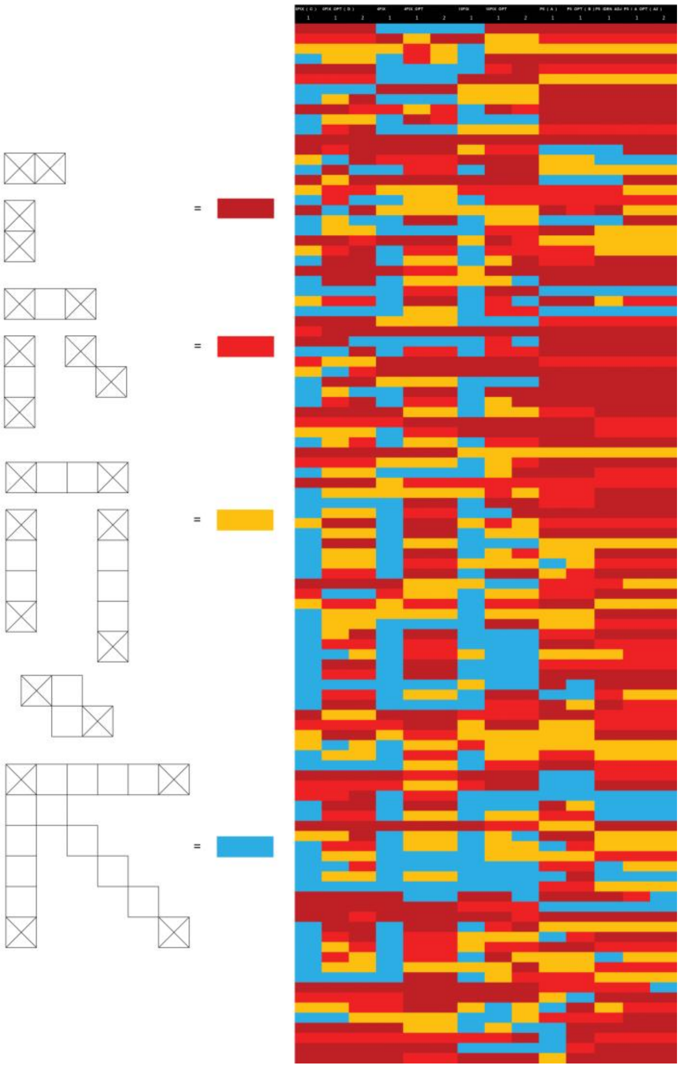

Fig. 7. Relation satisfactions of space layouts of QAP were checked visually by the designer. Only the strongest relations were rated according to their satisfaction. Colorswere given according to the final positions of the design units in the space layout on the left. Satisfied: Claret red, Partly Satisfied: Red, Unsatisfied: Yellow, Not related at all: Blue.Relation satisfactions color schema is on the right. Layouts from left to right:

1-a random layout, 2-optimization of 1, 3- a random layout with 4 design units fixed on the desired zones, 4-optimization of 3, 5- a random layout with 10 units fixed on the desired zones, 6-optimization of 5, 7-space layout of intuitive approach , 8-optimization of 7, 9-space layout of intuitive approach with identical units adjacently placed, 10-optimization of 9

From 1 to 10; relation satisfactions increase with the increase of designer control on the initial space layout. Drawn by the author.

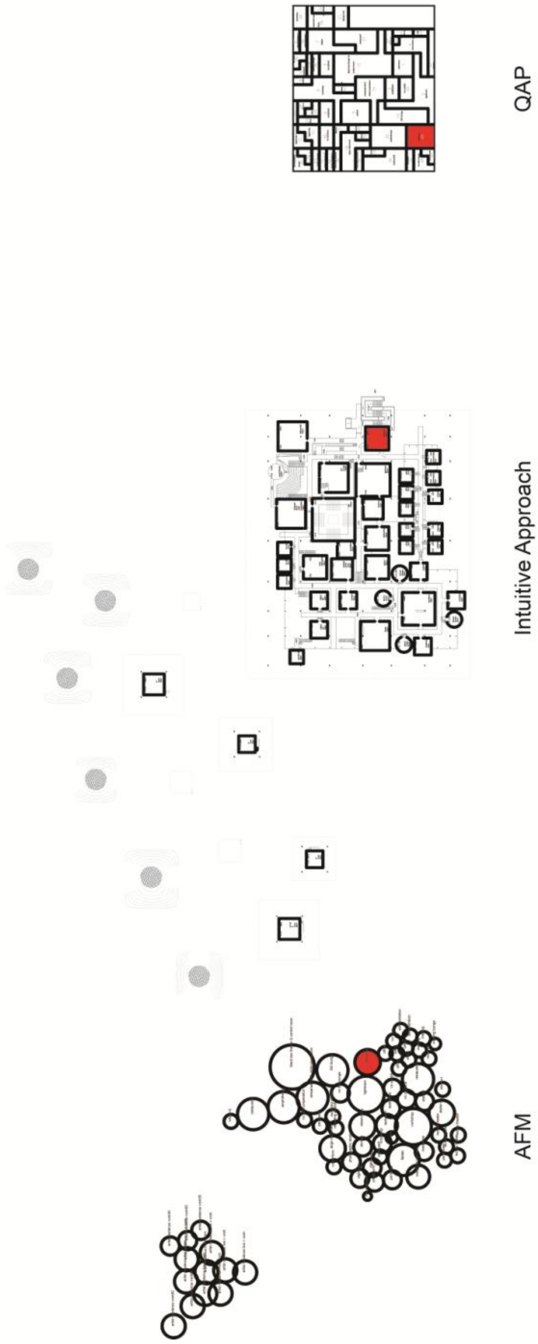

Fig. 8. There space layouts by AFM, Intuitive Approach and QAP from left to right. Entrance was highlighted with red in all layouts. Drawn by the author.

5 Conclusion and Future Work

The usefulness of computerized space layout programs are researched by using two computerized space layout approaches, AFM and QAP and an intuitive approach by one designer, in a design process of an actual problem of space layout of more than 50 design units of unequal sizes. In those three processes, the designer observes the input preparations, optimization and satisficing processes and resulting space layouts. The evaluations of the space layouts are based on both the satisfaction of the given input of desired relations and what the space layouts represented. Three space layouts were generatedas illustrated in Figure 8. The research showed that each approach uses different evaluation methods and representation approaches, which gave an idea to understand the potentials and disadvantages of the computerized space layout approaches and their convenience for various design states in the problem of space layout.

The intuitive approach develops the space layout gradually based on a search for satisficing solutions, while the computerized space layout approaches use optimization method and try to reach the best result. To take maximum advantage of the computerized approaches, the designer should modify their structure by multiple trials, adjusting and understanding the effects of the parameters. More alternatives the programs generate, less conditioning on the results. This is the biggest advantage of the computerized models over the intuitive approach. In this research, only QAP could generate alternative solutions with the given input and initial adjustments, nevertheless it is also possible to modify AFM and benefit from its potential.

The space layouts generated by the computerized models helped the designer in the solution of a complex problem. The results were reliable and helpful, especially after the familiarity of the designer with the model. So the discussion on the efficient solution of the problem by human or computer is not a question of the designer after this research. However the discussion on the usefulness of the computerized space layouts in the professional field still exists and the ways to improve the computerized space layout approaches should be the matter of discussion. The author agrees with the two recommendations of Lobos and Donath (2010) for architects and space layout researchers, where space layout researchers should try to reach architects by understanding their approaches about good and efficient architecture and reflect on that and architects should try to understand how space layout researchers approach to the problem of space layout.Computational approaches should be integrated in educational programs and merge with the traditional space layout methods. Architects representing this new trend may create boutique approaches for their own design processes, rather than expecting the space layout researchers to approach to their problems.

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Note

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