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Paper : **OPTIMIZATION OF USER ACCESSIBILITY USING GENETIC ALGORITM: ADA**

Topic: Architecture

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Abstract:
One of the most important criteria for spatial accessibility[1] is the complement of the movement in a shortest distance in a certain amount of time. However the shortest distance is a relative definition. In order to define the shortest distance in multi user spaces, optimization is necessary.

The aim of this study is the optimization[2] of user accessibility in architectural design field using a genetic algorithm[3]. In order to achieve this scope, a methodology called ADA (Algoritmic Distance Based Accessibility) is developed. This model will be introduced based on user movements and the spatial accessibility. Depending on movement analysis of different user types, relationship matrix will be created by optimization of movements on distance and time which is the basic data source for the design model to be developed. The developed plug-in, will generate optimum plan scheme based on spatial use data of users, evaluate fitness analysis of given plan scheme, and will be developed as a script to run on Rhino Grasshopper. In this methodology the process takes place in four steps:
(1) Obtaining user data: Definition of user types and their daily routes,
(2) Obtaining spatial data: Definition of main spaces, sub spaces and relationship parameters, user density, publicness/ security/ emergency levels, and evaluation of spatial accessibility parameters,
(3) Coding and optimization: Coding of flow charts in C# language, and optimization of the routes using a genetic algorithm in Rhino Grasshopper plug-in,
(4) Evaluation: Evaluation on predesigned projects, test of the model.

As for the results, the targeted outputs are as follows:
-To define spatial accessibility and determination of interdisciplinary relationship between design field and other fields (social, economic, cognitive)
-To state the contribution of user accessibility optimization model to architectural design field.
-To take into account of user movements, to develop the design model to use in preliminary design phase of large scale architectural designs such as campuses.
-To develop a model to evaluate predesigned or built architectural projects based on user movements.
-To evaluate the contribution of genetic algorithm as an optimization tool to architectural design field.

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Optimization of User Accessibility Using Genetic Algoritm: a*DA*

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Abstract

The aim of this study is the optimization of user accessibility in architectural design field using genetic algorithm. In order to achieve this scope, a methodology called **a*DA*** *(Algoritmic Distance Based Accessibility)* is developed. This model will be introduced by analyzing movements of different user types depending on spatial and user accessibility. Depending on movement analysis of different user types, a relationship matrix will be created by optimization of movements by means of travel cost in meters which is the basic data source for the design model to be developed. In this methodology the process takes place in four steps: (1) Obtaining user data, (2) Obtaining spatial data, (3) Coding and optimization, and (4) Evaluation. The developed plug-in run as a script on Rhino Grasshopper, evaluate fitness values of given plan scheme and generate optimum plan scheme based on user data.

Concerning the results, the advantages of the design data gathered by the optimization of user routes are accentuated. For future suggestions, it is indicated that within the computational design paradigm, the human factor should be taken into consideration along with the movement models, and its contribution to design knowledge. Besides it is emphasized that the movement optimization model could be efficient to use for the design of complex buildings such as hospitals since the method will be further enriched by testing the model on such building typologies.

1. Introduction

Accessibility has received considerable interest in society in recent years, not only a luxury response reserved for special communities [1] such as disabled people, but also an oppourtunity for all. The reason to support this rationale is more functional use of buildings, therefore “design for all” concept can be practiced widely in different building typologies.

Accessibility in architecture means more than spaces that can be used for all people equally [2]. Spatial accessibility, more than in and out relations of the space, is the concept which allows the user to understand function, organization and spatial relationships and welcome them to participate in activities [3]. Better understand the concept; data, communication, movement and facilities of the user should be well defined [2]. Therefore, concerning user and spatial accessibility in the buildings, one of the most important aspect is the movement of people to consider in the design methodology.

If there is an accessible path but it takes 10 times more time [1] to reach the destination, can this be considered accessible enough? Probably not. Therefore, one of the most important criterion for spatial accessibility is the complement of the movement in a shortest distance in a certain amount of time. However the shortest distance is a relative definition. In order to define the shortest distance in multi user spaces, optimization is necessary. In this sense to concentrate on this optimization problem, evolutionary algoritms are chosed to use in the method, since this approach is a generative testing tool[4] that fits the procedure of synthesis and evaluation in the design process.

Genetic Algorithms (GAs) is very well known evolutionary algorithms, which is widely used in design process. They are used as stochastic methods for solving optimization and search problems [5], and recent work has shown their simple but powerful search capability [6]. Genetic evolutionary design concepts have been applied in the design and architecture areas and had shown promising results [7,8,9,10,11,12,13]

Therefore, a study has been conducted in this perspective, to optimize user accessibility in terms of distance, in architectural design field using genetic algorithm. In order to achieve this scope, a methodology called a*DA (Algoritmic Distance Based Accessibility)* is developed. This model will be introduced by analyzing movements of different user types depending on spatial accessibility. Depending on movement analysis of different user types, a relationship matrix will be created by optimization of movements by means of travel cost in meters, which is the basic data source for the design model to be developed.

This study is divided in three main parts. The first part examines spatial accessiblity in terms of user movements and compares the studies in the literature. The second part examines genetic algoritms in architectural design field and optimization problems. Finally the third part explains the developed method, aDA, its background studies, data collection, process and results. Moreover the third part promotes a prospective use of the method in such complex building typologies, which will be further studied.

2. Analysis of Spatial Accessibility in Terms of User Movements

Even accessibility is challenging even for healthy people; abled/disabled and healthy/unhealthy people should be considered in terms of accessibility to every space. Communal space should be accessible not only to disabled but also to everyone [14]. Therefore, “accessibility for all” motto should be reconsidered in terms of architectural design.

To better define accessibility for all concept, It will be helpful to present the spatial acsessibility components and measures. Since buildings are service providers, their quality should be measured by defining a set of representative service paths [1]. Therefore it will be useful to analyze an existing methodology to measure spatial accessibility. There are 5 criteria which can be mentioned here: Counting, total sums of distance, closest activity, gross interaction potential, probabilistic choices (Table 1).

Table 1. Accessibility Measures [1,15]

Criterion	Definition	Accesibility Measure
Counting	Counting Accessible Locations for an activity	Accessibility increases directly proportional
Total Sums of Distance	Total distance to go	Accessibility increases inversely proportional
Closest activity	The situation of the closest activity being available	Accessibility increases inversely proportional
Gross interaction potential	Attractiveness, convenience and different number of activities	Accessibility increases directly proportional
Probabilistic choices	Among the activity potentials, the probabilistic choice	Accessibility increases directly proportional

Considering spatial accessibility, there have been previous studies [2,14,16,17,18,19,20,21]. Among these works, internal and external accessibility is defined and studied [16], horizontal and vertical circulation within the building is considered internal, relationship with the nearby environment and the town is considered to be external [17]. Studies considering internal accessibility focuses on accessible design criteria [21], theoretical and practical knowledge integration [2] and use of physical environmental data [19], orientation and user types [18] in hospitals. On the other hand studies considering external accessibility focuses on setting criteria in mass housing [14] and layout pattern evaluation [20]. As far as this paper focuses on internal accessibility measures and user movements, it is important to point out that accessibility should be considered in various parameters, but it is important to define proper evaluation criteria for the desired solution.

2.1 Developed methods for space planning and accessibility in the literature

There are many methods focusing on the place of accessibility concept in design, its development and generation. The ones we consider here are space layout planning, space syntax and wayfinding to overview.

Space layout planning is the assignment of discrete space elements to their corresponding locations while having relationships with each other [6]. The relationships include topology and geometry where topology implies using grammars and geometry implies mathematical programming or related optimization techniques [6]. There has been many researches on this issue [6,22,23,24,25,26] focusing on constructive placements, synthesizing layouts using generative grammers and use of genetic algorithms in topographical and geometrical problems. The planning problem points out three important aspects; how to formulate the problem, how to control the generated solutions and how to evaluate depending on various criteria [6].

The studies that focused on architectural planning order can be summarized as; the placement of rectangular units on a plan [27], planimetric parameter optimization [28], use of genetic algorithms with the method of activity grouping [29] and use of knowledge based systems in antropometric data base optimization [10]. In larger scale projects, a heuristical approach of ant colony optimization is used for relating activities and spaces in an office block [30]. The common result to be realized from these studies is to generate solutions based on specific parameters meeting fitness function requirements in architectural planning scale.

Another method to overview is space syntax, which is a research program to define the relationship between people and space within general theory perspective of building/ settlement/ city structure. The startup of the concept is the people using space as a key to organize for themselves [31].

There are many researches on interior space analysis, some of them are; comparison of two distinct office spaces (designed and built) via axial mapping [32], characterization of a space as a whole with graph spectra and plan generation via optimization with genetic algorithm [33] and an evacuation system proposal stressing spatial, ergonomical and cognitive parameters [34]. In this respect, additionally there are studies defining and practicing accessibility measures due to distance and time [35]. The common point of these studies is the feasibility of space analysis due to physical and sociological measures and the use of computational methods in space syntax methodology.

The studies doing compative studies concentrating on human movement are useful to inspire this research. One exemplar study make a comparative study of real and virtual environments and show the results of human movement to influence the spaces [36]. Whereas another one studies a virtual environment via wayfinding and compares the movement and cognition data [37]. The results shows us whether in a real or virtual environment, human movement is a key factor to affect the design methodology.

The final method to overview and compare within the literature is wayfinding. Being a concept relating environmental and behavioral studies, wayfinding is defined as the action to start from a departure to reach a target [38]. A successful wayfinding is a behaviour to know the location and best route, to follow, to recognize the target and to find the way back [39].

The studies regarding wayfinding are; evaluation of wayfinding concepts on the distance, user route and actions with observing human behaviours [39], wayfinding analysis of the users of before and after use of space [40], the factors to effect wayfinding behaviour, its impact on building configuration, visual accessibility, circulation systems and signs [41].

The above mentioned methods have shown us, there are multifold driving forces for an enhanced building accessibility. Among these forces, user data is important regarding the matching of the generative process to the architectural design process. In the following section we focused on genetic algorithms in architectural design field and optimization.

3. Genetic Algoritms in Architectural Design Field and Optimization

Genetic Algorithms, inspried by genetics, is a stochastic method for solving optimization and search problems, operating on a population of possible solutions [5], based on natural selection criteria. The process is based on probability rules with use of fitness function to search the related solution space [42], in a relatively shorter time [43].

As mentioned before, one of the most important criterion for spatial accessibility is the complement of the movement in a shortest distance in a certain amount of time. Since the shortest distance is a relative definition, optimization is necessary to define the solution. Searching for previous optimization problems, the example of a system of lineer inequalities can be taken as a good example for this paper's methodoogy. Among many possibilities of a movement route starts with a point and ends with a destination point, the problem is the total distance optimization (Figure 1).

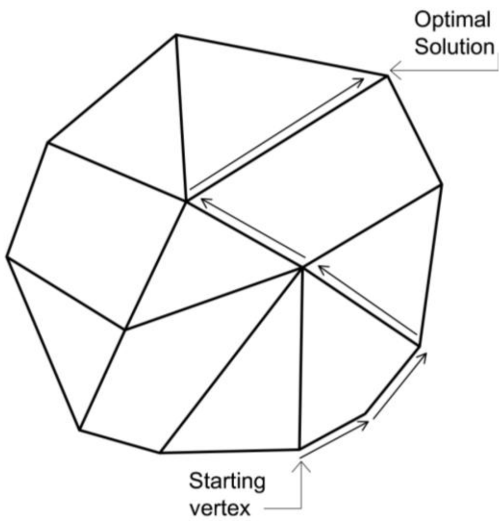

Figure 1. A system of lineer inequalities: It begins at a starting vertex and moves along the edges of the polytope until it reaches the vertex of the optimum solution[44]

Genetic algorithms are an appropriate form of communication [6] between the architectural design and genetic evolutionary processes. The studies in this the field of space layout problem solving and optimization can be summarized as; genetic optimization techniques used in space layout problems [6] and geometrical space planning via dimensioning of space elements [45,46,47,48]

The studies regarding architectural space can be pointed as; use of nature inspried genetic/evolutionary design model on space planning [6], a knowledge based system proposal on an optimal office layout [10], generation of space layout typologies for architectural plans with an evolutionary approach [11], use of genetic algorithms in space layout planning [29].

Since genetic algorithms are proposed to be the best tool to use in optimization problems in architecture field, it is used in the method we developed in the following section.

4. Algoritmic Distance Based Accessibility Model (ADA)

The aim of the developed method is to analyze user movements in the building environment in terms of accessibility and optimize the user routes due to accessibility criteria using genetic algorithm. Depending on the literature discussed before, the main problem in this work is optimization of user and spatial accessibility using distance data using genetic algorithm and transforming the data obtained into a design methodology.

In this methodology the process takes place in three steps (Figure 2):

(1) Obtaining user data: Definition of user types and their daily routes,

(2) Obtaining spatial data: Definition of main spaces, sub spaces and relationship parameters, user density, publicness/ security/ emergency levels, and evaluation of spatial accessibility parameters,

(3) Coding and optimization: Coding of flow charts in C# language, and optimization of the routes using a genetic algorithm in Rhino Grasshopper plug-in.

Depending on movement analysis of different user types, relationship matrix will be created by optimization of movements on distance and time. This matrix will be the basic data source for the design model to be developed. The procedure followed is the examination of user movements and development of their schemes in the flowchats (Figure 3) and drawing of the user speed/distance table (Table 2).

Table 2. User Types and Speed/Distance Table

		Healthy								Unhealthy							
		Disabled	Speed(m/h)	Min. distance(m)	Max. distance	Normal	Speed(m/h)	Min. distance(m)	Max. distance	Disabled	Speed(m/h)	Min. distance(m)	Max. distance (m)	Normal	Speed(m/h)	Min. distance(m)	Max. distance (m)
User A	Type1	o	300	3	75*												
	Type2					o	500	3	125*								
User B	Type3									o	200	3	33,3**				
	Type4													o	400	3	66,6**
		* For a healthy user, maximum walking time between two locations is accepted as 15 min.								* *For an unhealthy user, maximum walking time between two locations is accepted as 10 min.							

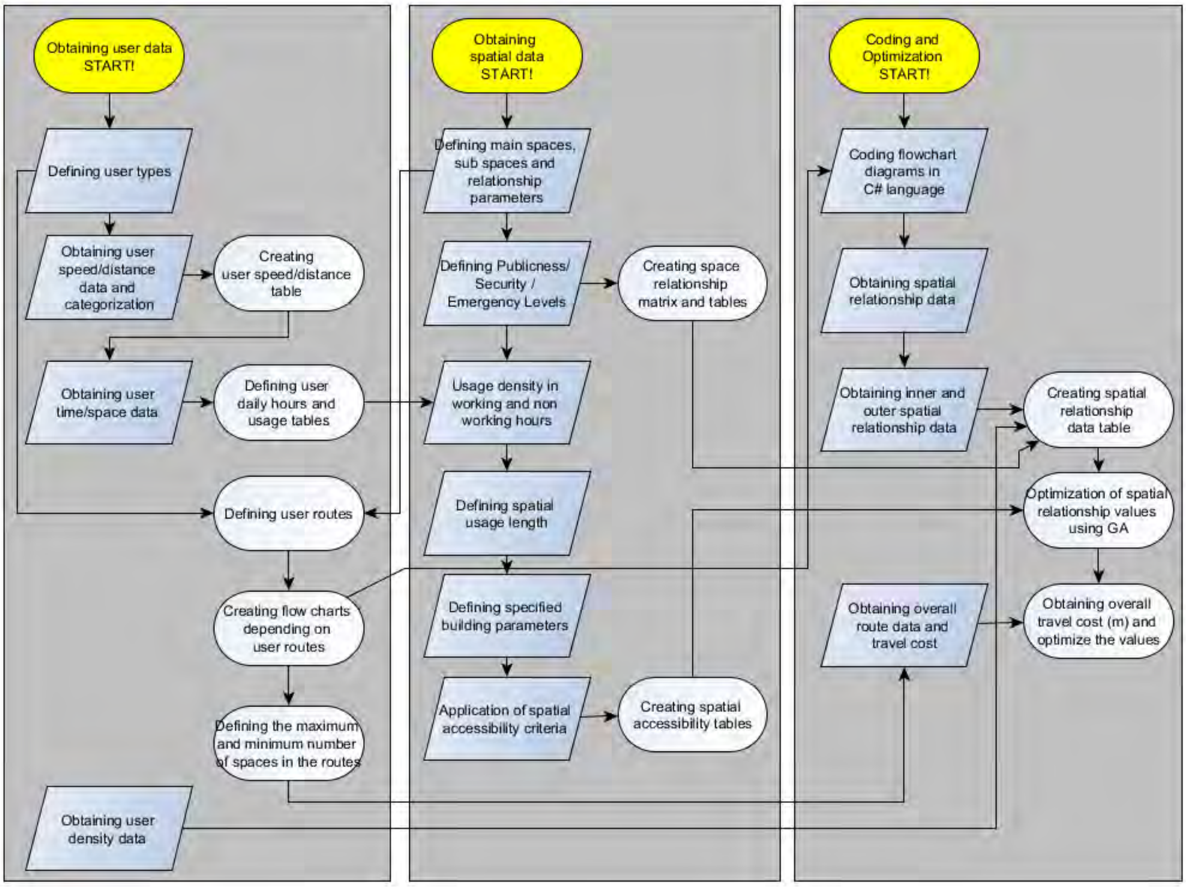

Figure 2. The Method Chart

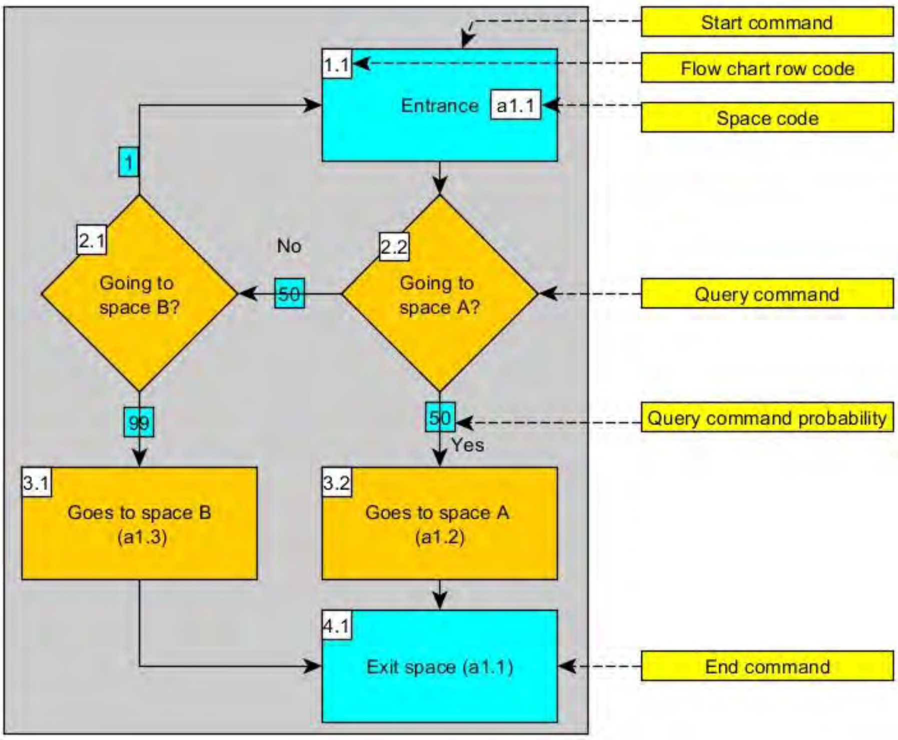

Figure 3: An example of a flowchart of a user route

Using these data sets, a simple genetic algorithm is designed with a special fitness function. Two components are generated in Rhino Grasshopper interface (Figure 4); *User Component* is used to process user movement data. The user component takes an xml file that includes node data and generates paths (Table 2). *Genetic Solver Component* is used to optimize the routes. It takes the user paths and relations and creates the coordinates for spaces using a genetic algorithm (Table 3).

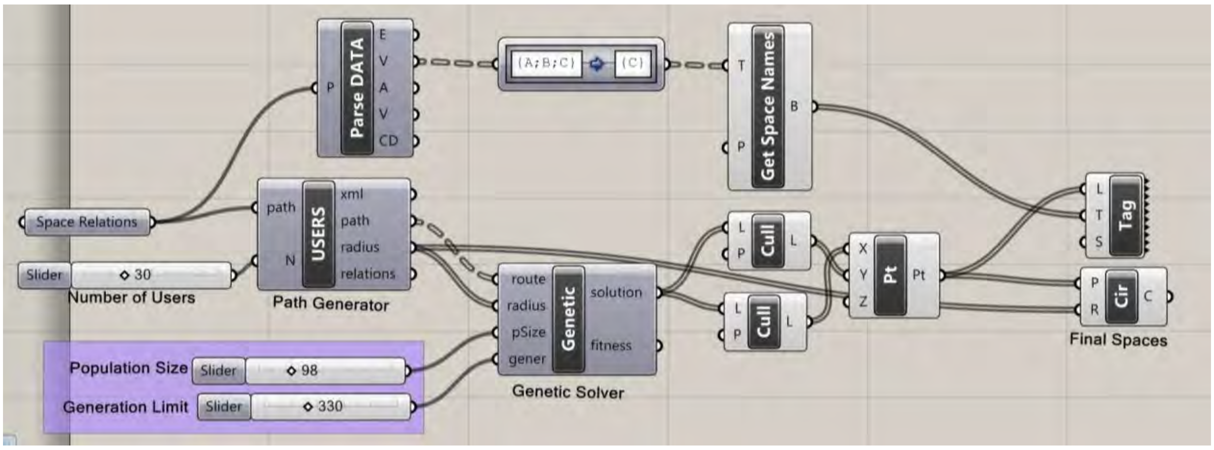

Figure 4. Rhino Grasshopper interface

Table 3. User Component

INPUT	*Type*	
XmlDocument	File	The xml file
Int	Number of users	The number of user paths to be generated
OUTPUT	*Type*	
DataTree<int>	Path	Generated paths according to probability schema
DataTree<int>	Relations	Relation degrees between spaces
String[ ] names	Nodes	Name of the nodes in paths.
Double[ ] radius:	Degree	Usage degrees of spaces.

Table 4. Genetic Solver Component

INPUT	*Type*	
DataTree<int>	Path	Generated paths according to probability schema
DataTree<int>	Relations	Relation degrees between spaces
Int populationSize	Population	Population Size of genetic algorithm
Int generations	Generation	The number of generations as termination criteria
OUTPUT	*Type*	
Double[ ] solution	Coordinate	Coordinates of spaces
Double fitness	Fitness	Fitness value of the solution

The Genetic Algorithm parameter selection criteria are the chromosome, addition mutation, multiplication mutation, crossover, fitness function and selection. *Chromosome* is defined by a array of doubles that represent x and y values of points. x and y values are stored consequently for each point. (x value =

chromosome[n] , y value = chromosome [n+1]). There is two types of mutation defined for this chromosome.

Addition Mutation is change of x and y values in a range. In this case the range domain is defined as (-20,20). When this number increased diversity increases in the population, and decreases in reverse. Convergence to optimum solution slows down in too high or too low values.

Multiplication mutation, multiplies x and y values in a chromosome with a number within the range (-5,5). Similar to addition mutation, different values effect the diversity and convergence.

Crossover is a single point crossover used in this algoritm.

Fitness Function is defined as a special one for this algorithm. The fitness function takes two consequent points in the chromosome and calculates distance. Then it subtracts the relation degrees between those points. This function repeats until the end of the chromosome. Finally, the fitness value is determined as 1 divided by the result (1).

$$result = \sum_{i=1}^{n} \sqrt{(x_i - x_{2i-1})^2 + (y_i - y_{2i-1})^2} \quad (1)$$
$$fitness = 1/(result - relationDegree)$$

Selection is defined as elite selection method for this algorithm.

The objective of the algorithm is to maximize the fitness function through generations. Our findings show that the algorithm successfully increases the fitness value, however most of the times there is no “perfect solution” thus it gives an approximation resulting with fitness values lower then 1 (Figure 5). Since the fitness function tries to make the results closer to relation degrees, end product is ideally a set of tangent circles, where every circle representing a space and the radius of it is the degree of usage (Figure 6). Genetic algorithm runs with specified population size until the specified generation. After the algorithm terminates, the genetic solver component writes the coordinate values as output. These values can be used to create spaces.

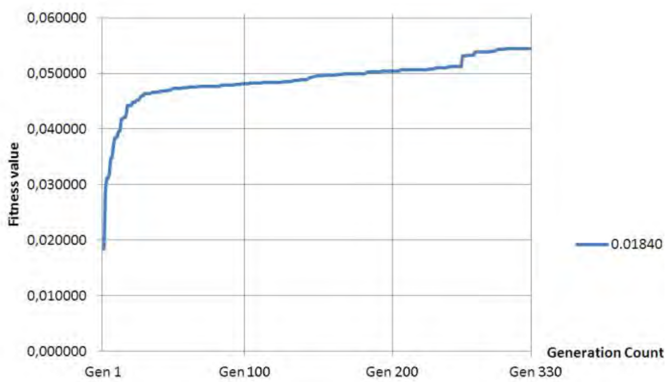

Figure 5. Fitness values and generations

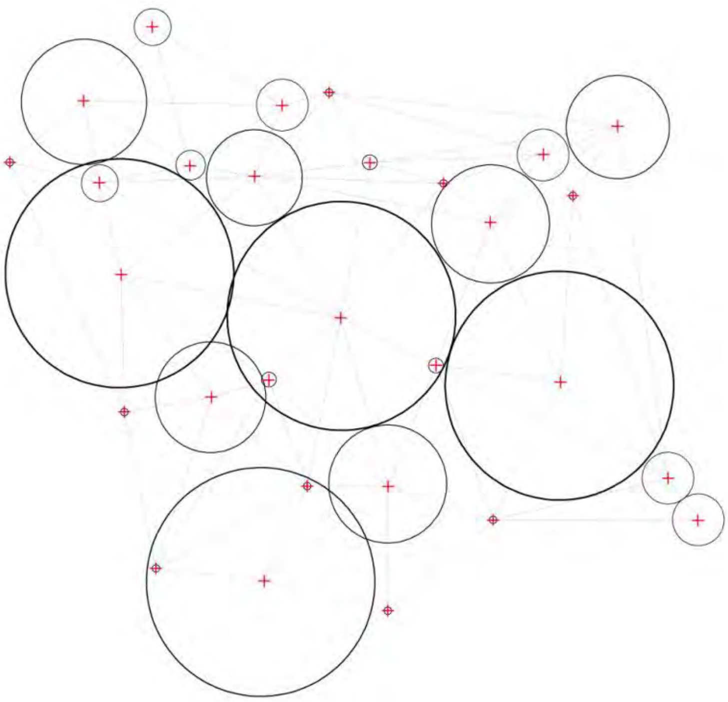

Figure 6. Final solution after 330 generations

5. Results and Prospective Studies

We used user movement diagrams and aimed to generate new planimetric possibilities towards an optimized behavior of the final configuration in site plan scale. We developed a script based tool that works as a component running in Rhino Grasshopper. This work focuses mostly on those aspects related to the user movement inside spaces.

As for the results, the targeted outputs are as follows:

-To define spatial accessibility and determination of interdisciplinary relationship between design field and other fields (social, economic, cognitive)

-To state the contribution of user accessibility optimization model to architectural design field.

-To take into account of user movements, to develop the design model to use in preliminary design phase of large scale architectural designs such as campuses.

-To develop a model to evaluate predesigned or built architectural projects based on user movements.

-To evaluate the contribution of genetic algorithm as an optimization tool to architectural design field.

The capability of producing optimized solutions and effective use of computational techniques for the given set of user data proves the utility of the developed model.

The utility of the model will be further studied and compared in complex building typologies such as hospital campuses.

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