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Solar exposure optimization potentials of the large modernist housing estates. The "*Tabula Rasa*" case

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Abstract

In the process of the city metamorphosis towards its self-sustainability a significant contribution would be to establish an optimal grade of urban density which would ensure the necessary amount of solar radiation needed to support the shift towards green energy production. Modern cities represent an assemblage of built heritage created through different periods and phases of evolution of the human society. The period which undoubtedly, significantly increased concerns over sustainability of our civilization is the large reconstruction and urbanization process started after the end of the World War II. The hyper-production of the large modernist housing estates between 1950's and 1980'years across Europe and worldwide left many cities with an enormous amount of significant energy consumers. Only in Germany, about 1,7 million living units were built. In Poland and Hungary about one third of the population (around 14 million) is living in such housing. Dominating tendencies regarding these housing districts could be divided in two direction: demolition and new development and thermal improvement and refurbishment of existing structures. Though, none of these approaches brought cities closer to the desired goal. In the aforementioned context and as a part of author's dissertation thesis which explore the optimization potentials and the future of these housing, this research will focus and explore the potentials of the first tendency.

Keywords – modernist housing estates; optimization; sustainability; solar neighbourhoods

1. Introduction

The latest directives of EU commission enforce the shift toward renewable energy resources, stating that all new buildings should reach the Nearly Zero energy standard by 2020 [1], and are re-opening the question of the efficiency and the future of existing building stocks. Current researches in the field of urban design are exploring different strategies how to improve the energy-efficiency of our cities. Regardless of the chosen aspect of analysis; thermal refurbishment and development of innovative retrofit façade solutions; establishing the optimal urban density and searching for balance between transport and building energy consumption [2,3]; solar potential of the urban morphology and improvement strategies of solar exposure in existing building environment [4,5,6]; the final goal is to make cities green and self-sustainable.

The future of the large housing estates depends largely on their potential to reintegrate themselves successfully into the newly proclaimed paradigm of self-sustainable society. In the period 1980-2000 a lot of energy has been invested in attempts to achieve a satisfactory energy-efficient reconstruction policy for these districts. These efforts have resulted with two dominating tendencies: demolition - which neglects the positive urban aspects and solar energy harvesting potentials of these housing estates; and energy-efficient refurbishment of the building envelope which tries to minimize the energy consumption and losses. Both of these approaches seem rather as forced solutions, than some cleverly planed strategies. In some cases is the process of their demolition inevitable. Due to stigmatization and bad reputation, significant number of these housing worldwide and especially in Eastern Germany, are abandoned and free for disposal. The most well-known examples of demolition were seen in St. Luis, USA on Pruitt-Igoe public housing district and on Bijlmermeer housing estate, in Amsterdam, Netherlands. They are replaced with newly planned mixed-use districts which usually follow the logic and the interest of the market and economic-efficiency and are characterized by extensive land use. The level of their sustainability is rather questionable. In the last few years, the development of solar technologies, including both photovoltaic and solar thermal technologies, have inspired advanced refurbishment approaches. Buildings with transparent insulation, that create thermal energy which is used for heating purposes, combined with PV based energy production and supported with other passive urban solar strategies have significantly contributed to the fact that in Salzburg, Austria we are witnessing a completion and monitoring of the first Active House Energy Standard single prefab housing unit. Furthermore, on a strategical planning level, there is ongoing research which aims to establish a "sufficiency factor" [7]. It should serve as evaluation tool for overall optimization of the refurbishment efforts based on combination of social, economic and energy-efficiency factors. Nevertheless, all of the previously described efforts, solutions and strategies, could be seen rather as pieces of a puzzle, building a final comprehensive strategy applicable on larger, urban scale.

2. Aim of the study

In order to develop a legitimate response and statement towards possible future of the housing estates, the author main goal is to confront two dominating tendencies demolition and reconstruction, under a premise of an energy-efficient development schema, and set up a new decision-making pattern for their future reconstruction policies. Thanks to both "Corbusian" urban design principles and urgent reconstruction demand, they could allow experiments both in the field of urban density and optimal solar exposure. For this purpose, within the frame of two mentioned extreme approaches, following 4 boundary scenarios were developed:

- **Scenario 1.** Total demolition (*"tabula rasa"* approach) – generating a new urban configuration with optimal solar exposure
- **Scenario 2.** Total demolition (*"tabula rasa"* approach) – generating a new urban configuration in accordance with the latest urban zoning regulations

- **Scenario 3.** Total preservation – generating supplements for existing urban layout; increase of the density under premise of optimal solar exposure
- **Scenario 4.** Partial preservation – approach which reinvestigates the existing context combining partial demolition and supplementary structures for existing urban layout; increase of the density under premise of optimal solar exposure.

These scenarios will serve to generate urban proposals which will be confronted and evaluated by using a set of given parameters such as **usable floor area, estimated solar radiation, estimated energy win, estimated energy consumption, grey energy consumption,** etc**.** The results will give an insight to which of the proposed scenarios is satisfying the desired goal of sustainability in the most efficient way. It should give an answer to the dilemma, whether reconstruction or to demolition is more sufficient approach, and could prefab housing development become a meaningful 2nd life. They should also indicate if current planning regulations are allowing the possibility to build optimal solar neighborhoods and under which circumstances is such development possible.

This paper will focus on the development of urban schema described in the first scenario. On an empty plot, the main task will be to create a new urban design which can achieve maximal radiation in wintertime in correlation with optimal density. Evaluation of the solutions will be done on a basis of total amount of radiation as well as radiation/m² façade surface ratio. Results will be used to select the adequate solution as a representative which will compete against other 3 scenarios in the future steps of the development of the dissertation. This geometrical optimization process will serve as a prerequisite for successive future BIPV and other solar based technology integration as a part of an overall concept for solar neighborhoods.

3. Research methodology and simulation process

Research model

For the research model has been chosen a specified part of the large modernist housing estate called Nordweststadt, located in the north-west suburban area of Frankfurt am Main city, in Germany. The selected area is designated with following streets: Ernst-Kahn-Straße on east, In der Römerstadt on south, Bernadottestraße on north and am alten Schloß on the west side. The housing was built in the period 1961-1972, as a part of the post-world-war reconstruction policy and is positioned adjacent to the famous “Ernst May Siedlung”, which was considered to be the first electrified large housing estate in Europe dating from 1929. The urban layout of the estate is configured as a pavilion type, and is created of mixture of housing units, public institution and supply facilities. Housing differ from single family objects to collective housing typologies in form of tower blocks mixed or small ensembles consisting 2-4 typologically same building units. In the selected area, 4 different prefab housing prototypes can be distinguished. For the purpose of this research and the "*tabula rasa*" approach, the existing structures and greenery on the site are considered as demolished.

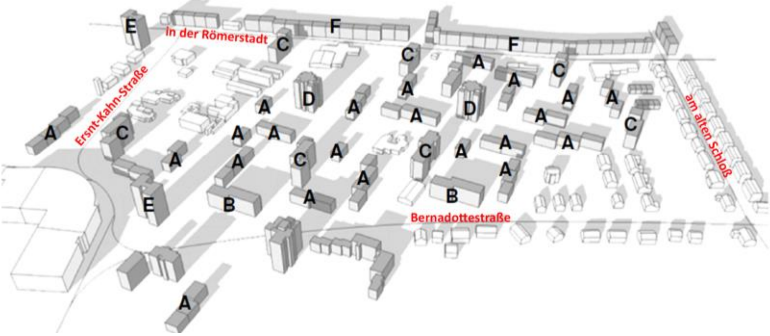

Fig. 1 3-Dimensional model of the analyzed location with marked prefab housing units

Boundary conditions

Due to complexity of conditions influencing the process of urban design in practice, urban development in the proposed research scenarios should be seen rather as a part of the methodological approach used to determine the optimal density, than as a finished urban proposal which considers all the social and human aspects of the urban planning, directly applicable in real conditions. Models are represented through generic urban layout, which was created using 3 different collective housing typologies – tower block, linear block housing and perimeter block housing with following geometrical constraints:

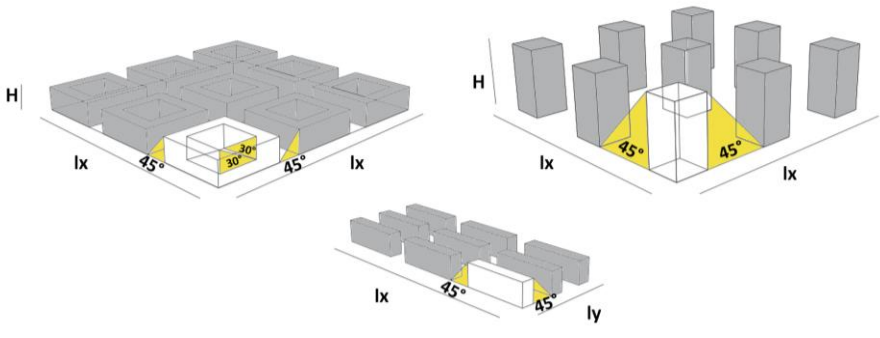

Fig. 2 Geometrical constraints applied on each typology

These 3 typologies were distributed on the square field sized 270x270m. The length dimension represent the shortest distance on the analyzed field along the Am Alten Schloß street. Due to specific design process this length was sufficient to test the rules which could be applied on the whole site. Around the experimental field was built context geometry to represent the shading factor of the existing structures along the 3 boundary streets. As a precondition for optimal solar exposure and usage of PV on facades the solar inclination angle shouldn’t extent the range between 30°-45° degrees. Angles between 0°-30° degrees [8] don’t contribute significantly to solar energy harvesting potential. Due to desired maximal density which secures the biggest amount of façade surfaces, this angle has been set to 45° degrees as a constant for the street profiles, while perimeter blocks have 30° degrees inclination in the courtyard area. Therefore the maximum height of the buildings and the size of the street profiles are dependent on the amount of typology units spread on the experimental field.

Simulation tool and conditions

The simulation of the scenarios was conducted using Grasshopper software including its components Ladybug [9]. Ladybug as a weather analysis plug-in tool can read **EPW *files*** containing weather data for any given location in the world and use them for simulation process. For the purpose of these research it has been used to calculate the total amount of solar radiation influencing the buildings on the designated area in two representative time periods. For the winter simulation process has been selected month December due to lowest sun position during the year, and in the summer period - June due to sun highest position.

4. Results and conclusions

In the first stage geometrical tests on the representative area were done using matrices, ranging from 1 (270m x 270m) to 6 fields (45m x 45m), with predefined building typologies in order to capture the relations between the amount of built area, number of stories and the façade surfaces they generate for each of them respectively. Matrices with more fields weren’t giving geometrically meaningful results which could represent a certain building type. The aim was to create a built area with biggest possible façade surface eligible for maximum solar win. In the second stage generated geometries were tested for their solar exposure potentials.

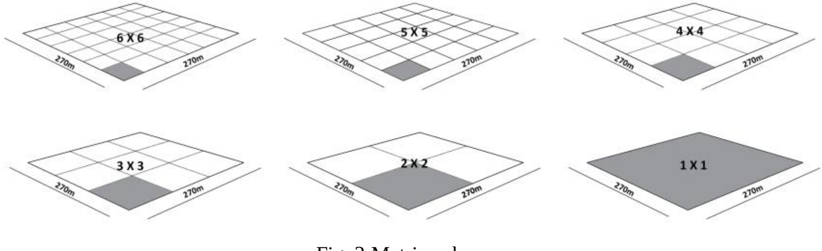

Fig. 3 Matrix schemas

Tower block

Detailed overview of the parameters for each matrix can be seen in the Table 1.

It if consisted of input data such as generated height, length and number of stories needed to build the research model, as well as outputs serving to compare them based on gained façade surface and floor area.

Table 1. Tower block geometrical features

matrix	Number of objects	Plot size m	Building height m	Building length m	Number of stories	Built area m²	Surface area m²
1x1	1	270	240	30	80	72000	28800
2x2	4	270	105	30	35	126000	50400
3x3	9	270	60	30	20	162000	64800
4x4	16	270	37,5	30	12,5	180000	72000
5x5	25	270	24	30	8	180000	72000
6x6	36	270	15	30	5	162000	64800

By analyzing the results collected for the tower block typology it is easy to distinguish that maximum density could be reach both with 5x5 and 4x4 urban matrix. The total amount of floor area and façade surface gained is identical in both cases. This evolution process is clearly represented on the Fig. 4.

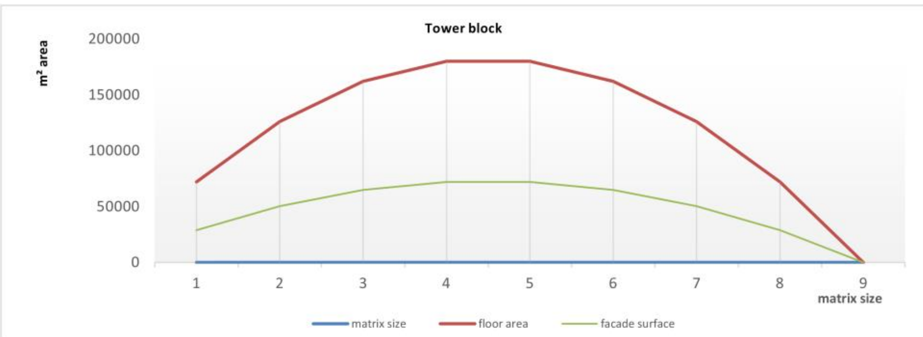

Fig. 4 Relation between matrix size and density-tower block

In the Table 2 are summarized results of the solar radiation simulations for the 2 best scenarios from the geometrical optimization. Simulations were performed for three characteristic angles, 0°, 22,5° and 45° which indicate different sun orientation of analyzed structures. The 0°angle simulation represent 4 façades facing frontally E, W, N and S side. Other two are rotated for the selected angles and therefore are exposed to two sides (N-E, N-W, S-E, S-W)

Table 2. Tower block radiation analysis

Angle	0°			22,5°			45°		
matrix	Rad.w. kwh	Rad.s. kwh	W/F kwh/m²	Rad.w. kwh	Rad.s. kwh	W/F kwh/m²	Rad.w. kwh	Rad.s. kwh	W/F kwh/m²
4x4	588520	3250000	9,08	594404	3350000	9,18	629421	3410000	9,71
5x5	480171	2950000	6,66	499203	3040000	6,93	525837	3130000	7,30

Despite of equal amount of façade surface the 4x4 solutions thanks to bigger street profiles generate over 100000 Kwh only in winter period. It also has significantly better level of radiation per m² façade surface. Sun orientation which provides the best conditions for this typology is achieved with 45° angle rotation (Fig. 05).

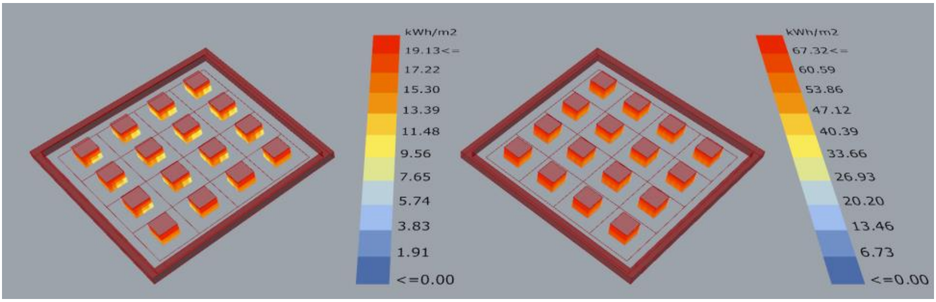

Fig. 5 Radiation legend - tower block; December (left) and June (right)

Perimeter block

Geometrical characteristics of the second typology are shown in Table 3.

Table 3. Perimeter block geometrical features

matrix	Number of objects	Plot size m	Building height m	Building length m	Courtyard size m	Number of stories	Built area m²	Surface area m²
1x1	1	270	90,1	179,9	155,9	30	242056	121028
2x2	4	270	40,7	94,3	70,3	13,6	214266	107133
3x3	9	270	24,2	65,8	41,8	8,1	187379	93689
4x4	16	270	15,9	51,6	27,6	5,3	161394	80697
5x5	25	270	11	43	19	3,7	136312	68156
6x6	36	270	7,7	37,3	13,3	2,6	112132	56066

In the case of perimeter block typology the density linearly reduces with the increase of the number of fields in the matrix and the amount of building units. The best features are notices in the case of one 30 storey high perimeter block with 30 stories. Building of such configurations is highly unlikable in reality therefore this solution is not considered as usable candidate for the next round. In the next round have been tested matrix with 2x2 and 3x3 field.

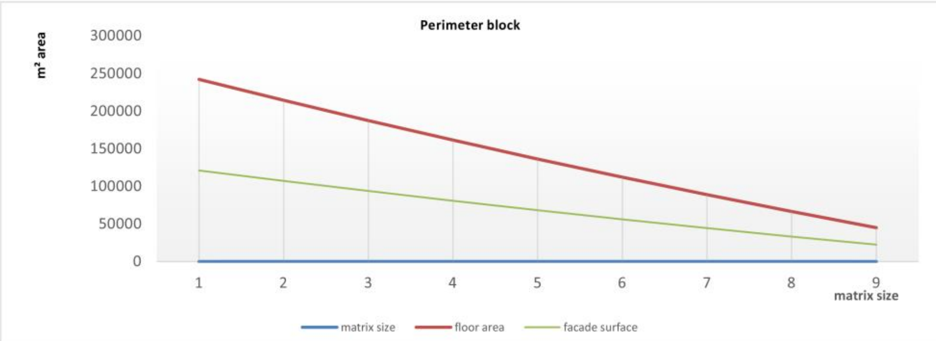

Fig. 6 Relation between matrix size and density-perimeter block

Table 4 are shows results of the simulations for the 3 chosen scenarios from the geometrical optimization. As in previous case simulations were done for three characteristic angles, 0°, 22,5° and 45° and already described sun orientations.

Table 4. Perimeter block radiation analysis

Angle	0°			22,5°			45°		
matrix	Rad.w. kwh	Rad.s. kwh	W/F kwh/m²	Rad.w. kwh	Rad.s. kwh	W/F kwh/m²	Rad.w. kwh	Rad.s. kwh	W/F kwh/m²
2x2	769546	4470000	7,18	775313	4520000	7,24	791175	4550000	7,38
3x3	576275	3650000	6,15	588207	3700000	6,28	609564	3760000	6,51

Although the facts show that winter radiation/m² ratio (W/F) doesn't differ significantly between 3 models due to obvious difference in built area and surface, 2x2 perimeter block solution with 95m length, 13 stories high and 45° rotation angle is seen as most optimal in this category (Fig. 07)

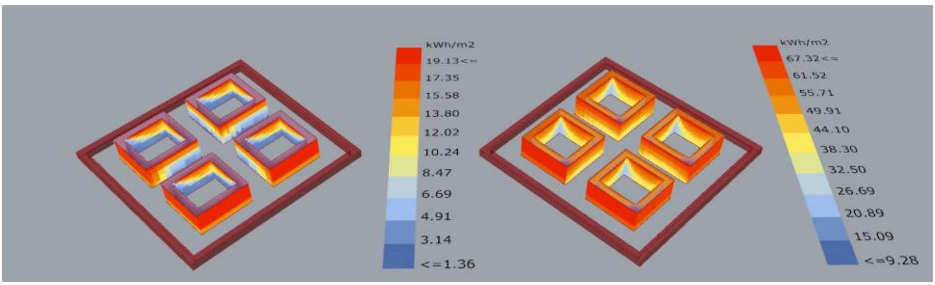

Fig. 7 Radiation legend - perimeter block; December (left) and June (right)

Linear block

In the case of linear block set of geometry data is provided in Table 5

Table 5. Linear block geometrical features

matrix	Number of objects	Plot size m	Building height m	Building length m	Building depth m	Number of stories	Built area m²	Surface area m²
1x1	1	270	129	135	12	43	69660	37926
2x1	2	270	123	135	12	41	145800	72324
3x1	3	270	78	135	12	26	126360	68796
4x2	8	270	55,5	79,5	12	18,5	141192	81252
5x3	15	270	42	48	12	14	120960	75600
6x4	24	270	33	34,5	12	11	109296	73337
7x5	35	270	26,6	27,4	12	8,9	102034	73602

Density in this particular case is largely affected by the number of units possible to distribute in constrained area. For this reason the linear representation in Fig. 08 has two jump points which indicate the best values. As in previous cases these two models were also analyzed from solar exposure aspects.

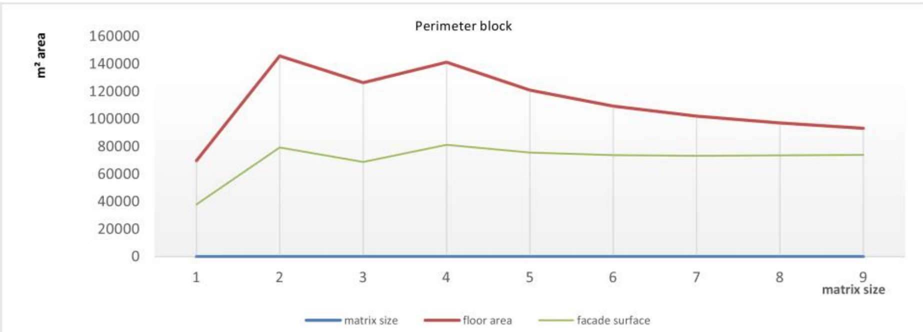

Fig. 8 Relation between matrix size and density-tower block

Interesting in this particular case is that the most optimal angle for best solar exposure is win 0° which suggest N-S orientation of main longitudinal facades.

Table 6. Linear block radiation analysis

Angle	0°			22,5°			45°		
matrix	Rad.w. kwh	Rad.s. kwh	W/F kwh/m²	Rad.w. kwh	Rad.s. kwh	W/F kwh/m²	Rad.w. kwh	Rad.s. kwh	W/F kwh/m²
2x1	824554	3370000	11,40	643612	3920000	8,89	742863	3860000	10,27
4x2	742583	350000	9,13	739979	3630000	9,10	729048	3830000	8,97

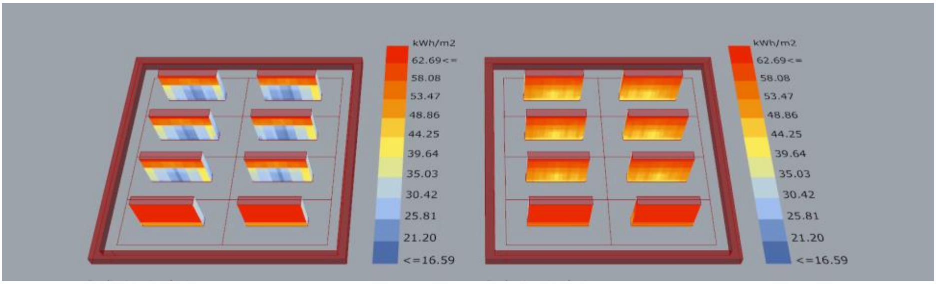

Fig. 10 Radiation legend –linear block; December (left) and June (right)

Although in this case the 2x1 matrix solution generated better results, in this category is chosen 4x2 raster due to more appropriate urban configuration.

Confronting 3 analyzed typologies results show that the perimeter block typology ensures biggest density and solar gains. In future development it will be used to create "*Tabula rasa*" Scenario 1 and confront it with the other scenarios

Gained knowledge and conclusions will be also especially helpful for the future works on this topic especially in process of creation of last two scenario, which will explore suitable reconstruction and densification policies.

Acknowledgments

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