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Energy retrofitting of dwellings from the 40's in Borgata Trullo - Rome

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Abstract

Buildings with architectural constraints and recognized historical values entail careful design process, especially, when the aim is to improve the energy efficiency. Foreseeable interventions consist of preservation and improvement of building envelope energy performance as well as the adaptation of the built environment to modern use and its accessibility. The compatibility between the aforementioned constraints and its future more sustainable use represents the crucial challenge. In this paper, feasible interventions on the dwellings from the 40's in Borgata Trullo, Rome were designed and analyzed. Public housing asset is an interesting environment to test a sustainable holistic approach due to its homogeneity in terms of building technology solutions and typologies. Furthermore, the absence of public funding made more difficult the ordinary and extra-ordinary maintenance processes. So, the approach accounts for the age of the building along with the subsequent reduced energy performance as well as the architectural values to preserve. The proposed energy retrofitting measures are related to the building envelope, in the installation of insulation layers, the substitution of windows and improvement of HVAC systems to enhance energy efficiency. Besides the case study, design guidelines were presented to help the stakeholders in compatible and sustainable interventions. New HVAC solutions showed high gains in energy saving even if building envelope modifications were limited by the willing to preserve the cultural heritage values. Therefore, a virtuous restoration can address effectively current energy efficiency targets.

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1. Introduction

Prioritizing sustainable urban regeneration can be considered the strategy to unlock urban resources towards healthy [1] and low-energy built environment [2]. Especially in highly urbanized areas, urban policy is definitely developing guidelines and best practices to address new issues such as outdoor thermal comfort [3], adaptation strategies to climate change [4] and more complex preservation measures for existing and listed buildings [5,6].

Today, the concept of urban renewal works with socio-economic regeneration and environmental impact, through appropriate energy improvement strategies and resource management but keeping in mind the preservation of historical, social and cultural values [7]. Old buildings, such as the ones built in the 60's to face the rising demand for housing, have often issues to be identified as cultural heritage rather than built environment no more suitable for modern society. Maintenance and refurbishment is the logical demand of this housing stock since many building components already reached the end of their useful life [8].

Beyond this critical issue, even where durability of materials is preserved, the design of those buildings entails high-energy consumption, spatial layout not suitable for modern society as well as neglecting many requirements obligatory according current regulations. Heading towards low or nZEB status is an achievable target if an integrated renovation is coupled with the analysis on energy production side as well as thermal management strategies [9,10].

The main lack in regulation is that the refurbishment framework from an energy point of view is the same for all building types, merging new constructions with large perspective of energy savings with listed buildings where even ordinary maintenance can negatively affect its preservation in terms of historical and architectural values. However, it is not realistic to push listed buildings to have energy performance as new buildings as well as adopting complex methods to explore energy saving potential [11]. Only, thanks to a careful and accurate planning of interventions can achieve optimal results from all points of view as already demonstrated in [12,13].

In order to assess the feasibility of urban regeneration Borgata Trullo was selected as case study. It is a public housing district built in the 40's in Rome, which is a representative example of the heterogeneity of case studies in Italy. This study is part of a comprehensive work done on public housing in Rome [14].

2. Borgata Trullo

Borgata Trullo is located in the south-west part of Rome, currently belonging to the Municipio XI, an administrative division of Rome Municipality. It takes its name from an ancient Roman tomb located on the right bank of the Tiber River. During the First World War, the Trullo area was the place chosen to locate the first industrial settlements. In 1917, Gaetano Maccaferri reclaimed land to build a barbed-wire factory for the military defence. Then, the Defence Ministry chose this area to set a branch of Genio Militare. Moreover, the area was also involved in the urban transformations for the Universal Exhibition of 1942.

In 1939, the fascist Independent Institute of public housing built up low-cost housing complexes, called borgate, composed by three villages: Torre Gaia, Quarticciolo and Trullo. The future users of those buildings were Italian settlers from France, Algeria, Egypt, Morocco and Tunisia. In detail, Borgata Trullo was designed as a complex of 336 apartments, divided into three main lots: one central plot, a southern lot and a northern one [15,16].

The Borgata was provided with roads, water and electricity services. Roberto Nicolini and Joseph Nicolosi were the designers following modern criteria and allusive architectural language to the rationalists themes. As shown in Figures 1 and 2, different kind of spaces were designed such as the balcony and staircase, kitchen gardens and private gardens were built. Great part of the buildings is composed by two or three floors with a specific focus on orientation to North-South and East-West for increasing the received solar radiation.

The buildings were conceived as the combination and series of two modules, called QE and QS. The QE contains four apartments per floor, each one consisting of three rooms and accessories, served by balcony with access from a single head-scale, as shown in Figure 3.

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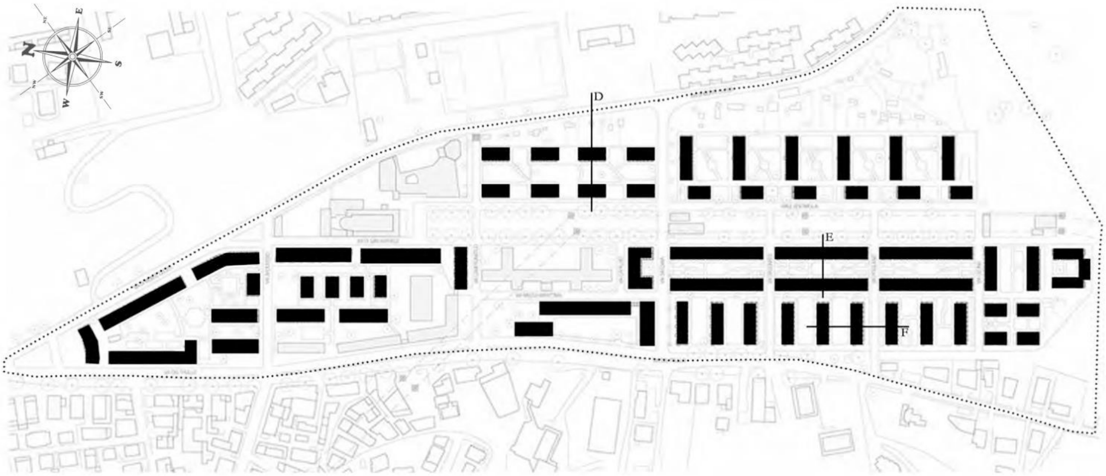

Fig. 1. Architectural plan of Borgata Trullo.

Fig. 2. Top view of Borgata Trullo in the '40s.

The buildings were conceived as the combination and series of two modules, called QE and QS. The QE contains four apartments per floor, each one consisting of three rooms and accessories, served by balcony with access from a single head-scale, as shown in Figure 3. While, the QS contains three apartments per floor: a small one com-posed by two rooms, a tiny kitchen and rest room with a surface of about 50 sq.m. and two symmetrical apartments at each side of the small one with a bigger kitchen. The wall stratigraphy and the structure were made by tuff masonry and bearing walls in pumice concrete, respectively. The floor was built as reinforced concrete slabs and pots of pumice conglomerate. Then, the sanitary consists of toilet, sink and shower. In 1940, Borgata Trullo was further developed but with the aim to reduce iron and concrete use.

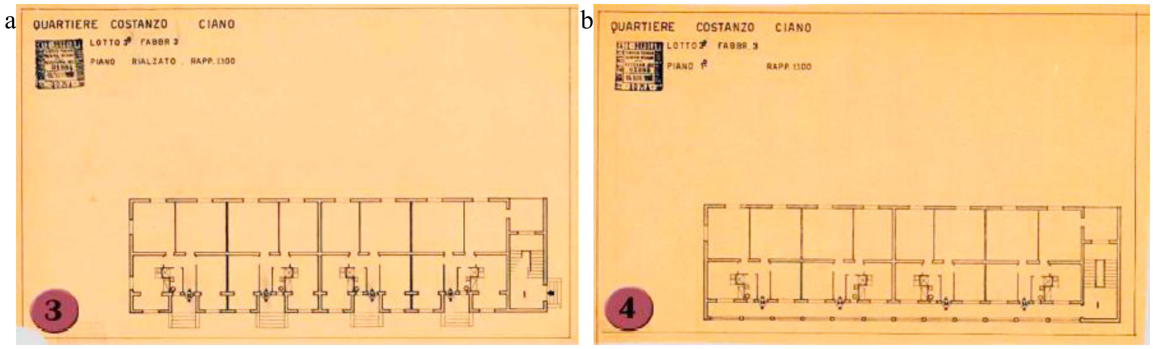

Fig. 3. *QE: Ground floor (a) and First floor (b)*.

Later on, nearby the original settlement of Borgata Trullo, new public housing interventions were added as well as a huge amount of informal buildings.

3. Status quo

Before the refurbishment design, a study on the thermo-physical characteristics and the installed HVAC systems was carried out by means of on-site survey, as reported in Figure 4. Furthermore, related bibliography as well as original architectural drawings were analyzed along with infrared camera use and surveying the inhabitants.

Fig. 4. Current views of Borgata Trullo.

The critical thermal singularities were determined by the thermographic survey of the building envelope in order to detect the modifications to the building components during the years: e.g. the substitution of window. In addition, onsite campaign allowed to identify new installed HVAC units such air conditioning units as depicted in Figures 6 and 7. A first information related to the building envelope is its low insulated layout both for opaque and transparent surfaces. Indeed, insulation layer is absent in great part of the buildings. The absence of horizontal plane as shading device does not protect the buildings from overheating phenomena occurring during the summer since the windows solar gain factor is high, around 0.80.

Table 1 reports the U-value of all the building components.

Table 1. U-value of building envelope components.

Description	Thickness [m]	U [W/m^{2}K]
Bearing walls in pumice conglomerate and brick	0,60	0,92
Low ventilated slab, no insulation, covered by granite flooring	0,32	1.38
Flat roof, no insulation, reinforced concrete and pumice pots	0,35	1,54

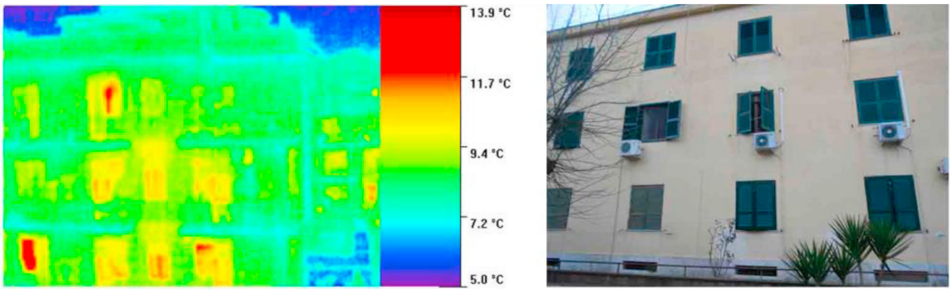

Fig. 5. Infrared and normal picture of South Elevation.

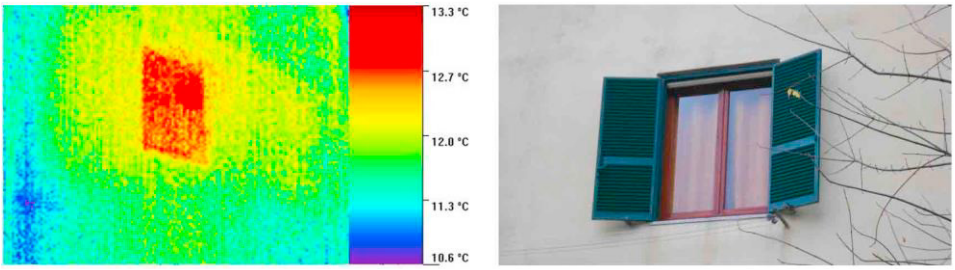

Fig. 6. A detail of Infrared and normal picture of South Elevation.

Fig. 7. Chimney and external air conditioning terminals.

The original HVAC system was composed by centralized heating system and autonomous domestic hot water production. During the years, in many buildings independent gas-boilers were installed for each flat so as to determine the interruption of centralized heating system supply. Those boilers were mainly located in the balcony. High temperature water supply for space heating was organized in a main duct located in the ground floor and columns to distribute it to the radiators. This entailed that in the detachment from centralized heating system a new distribution system was built in the apartments along with occluding the original columns. The cooling system was not included in the original configuration. Then, split-units systems (air-to-air heat pump) were added entailing changes in the facade aspect by the introduction of external terminals as shown in Figure 7.

The Italian laws [17] refer for both energy certification and energy audit process to the National technical standards UNI / TS 11300, which is the adoption of EN ISO 13790. It accounts for a monthly-based static method to calculate heating demand but, if preferred by specialists, it promotes the use of more detailed dynamic-based simulation methods. The use of dynamic methods, however, requires more technical knowledge and often is more time-consuming. A good compromise is the simulation tool ArchiEnergy which allows you to perform one-zone hourly dynamics simulations and to perform economic evaluations of the investments, including incentive system in force in Italy [18]. For the diagnosis of the building case study it was decided to use the simplified dynamic method since the static analysis is not able to take into account crucial factors. Table II reports the results of performed simulation for a reference building.

This latter is composed by three floors, each one with four apartments. Heating supply is provided by a centralized gas boiler while, domestic hot water is supplied by individual electric boilers. Radiators are the heating terminals and regulation is driven by the thermostat installed in the boiler.

Table 2. Results of performed simulation.

	Heating demand [W/m^2]		Primary Energy [kWh/m^{2}y]		Seasonal efficiency of heating system [%]	Total Primary Energy [kWh/m^{2}y]
	Winter	Summer	Winter	Summer		
Apartment 1 - 1st f.	69.7	51.3	65.5	31.0	48.5%	141.7
Apartment 2 - 1st f.	63.6	51.3	54.3	32.2	46.9%	121.6
Apartment 3 - 1st f.	63.6	51.3	54.3	32.2	46.9%	121.6
Apartment 4 - 1st f.	72.3	53.9	65.8	36.2	48.7%	141.9
Apartment 1 - 2nd f.	47.5	51.6	25.2	38.2	41.0%	64.6
Apartment 2 - 2nd f.	41.5	51.6	15.8	42.3	37.6%	44.2
Apartment 3 - 2nd f.	41.5	51.6	15.8	42.3	37.6%	44.2
Apartment 4 - 2nd f.	50.2	54.3	25.8	44.5	41.6%	65.2
Apartment 1 - 3rd f.	68.0	60.5	59.7	45.8	48.3%	129.8
Apartment 2 - 3rd f.	62.0	60.5	48.2	48.0	46.8%	108.1
Apartment 3 - 3rd f.	62.0	60.5	48.2	48.0	46.8%	108.1
Apartment 4 - 3rd f.	70.6	63.2	59.4	51.6	48.7%	128.0
Building	59.4	55.1	44.8	41.0	46.3%	101.7

As depicted in Table 2, the energy consumption is aligned with the typical value for buildings of the same age. Building envelope is clearly not equipped with insulation as well as a no effective regulation system. This latter entails an average efficiency of the regulation system around 67% due to the lack of thermostat in the indoor rooms. According to Italian Energy Performance Certification System, the building has the label G. A preliminary estimation of the cost for gas supply corresponds to about 6,300 €/year.

4. Energy refurbishment proposals

Starting from the energy status quo and accounting for the architectural constraints, two aspects were investigated for energy refurbishment interventions:

- a first solution is to improve building envelope thermodynamic performance in order to reduce heating and cooling demand as well as increasing the effects of passive solutions;
- a second aspect is to design the improvement strategy on the HVAC system side in order to increase the production efficiency, integrate a higher share of renewables to meet building energy demand. Specifically, two options were considered for installing high efficiency heating systems. Those measures entail different investment costs and change in building performance.

4.1. The insulation layer

As regards the building envelope, considering the smooth and plastered facades and a flat roof, an insulation layer for opaque walls and an upside-down roof solution to cover all around the building, as shown in Table 3.

Referring to the windows, a double-glazing wooden solution with argon gas in the cavity and glasses covered by a double low emissivity (g=0.20) and solar controlled layers was hypothesized.

Table 3. U-value of each building envelope components in the refurbished configurations.

Description	Thickness [m]	U [W/m^{2}K]
Bearing walls of pumice conglomerate and bricks, insulated with expanded polystyrene (7 cm) and plaster	0.67	0.38
Low-ventilated slab covered by granite flooring, insulated by expanded polystyrene (8 cm) and plaster	0.41	0.33
Flat roof in reinforced concrete and pumice pots, insulated by expanded polystyrene (8 cm) covered by granite flooring	0.43	0.31
Double-glazing wooden window with glasses covered by low emissivity (g=0.20) and solar controlled layers	-	1.54

The hypothesized insulation measures allow a high improvement in passive building envelope performance, especially referring to winter season, as shown in Table 4.

On average, the winter heat load changes from 59.4 to 28.3 W/m^2, showing a reduction of 52% while, the summer heat load varies from 55.1 to 37.1 W/m^2 with a reduction of 33%. Moreover, the heating demand decreased from 44.8 to 14.0 kWh/m^{2}y, i.e. around 69% while, cooling demand is almost halved from 41.0 to 22.7 kWh/m^{2}y.

From an economic point of view, the investment cost associated to this refurbished building envelope solution is equal to 135,000 €, deriving from a parametric cost of 70€/m^2 for insulation in vertical opaque walls, another one of 80€/m^2 for insulation in horizontal roof and, finally, a parametric cost of 400€/m^2 related to the window substitution.

Table 4. Results of Performed simulation of refurbished scenario.

	Thermal load [W/m^2]						Primary Energy [kWh/m^{2}y]					
	Winter			Summer			Winter			Summer		
	Ante	Post	Δ	Ante	Post	Δ	Ante	Post	Δ	Ante	Post	Δ
Apartment 1 - 1st f.	69.7	30.8	-56%	51.3	35.8	-30%	65.5	18.6	-72%	31.0	19.1	-38%
Apartment 2 - 1st f.	63.6	28.3	-56%	51.3	35.8	-30%	54.3	14.3	-74%	32.2	20.1	-38%
Apartment 3 - 1st f.	63.6	28.3	-56%	51.3	35.8	-30%	54.3	14.3	-74%	32.2	20.1	-38%
Apartment 4 - 1st f.	72.3	31.8	-56%	53.9	36.9	-32%	65.8	18.6	-72%	36.2	21.5	-41%
Apartment 1 - 2nd f.	47.5	25.5	-46%	51.6	35.7	-31%	25.2	9.9	-61%	38.2	21.6	-43%
Apartment 2 - 2nd f.	41.5	23.0	-45%	51.6	35.7	-31%	15.8	6.3	-60%	42.3	23.4	-45%
Apartment 3 - 2nd f.	41.5	23.0	-45%	51.6	35.7	-31%	15.8	6.3	-60%	42.3	23.4	-45%
Apartment 4 - 2nd f.	50.2	26.6	-47%	54.3	36.8	-32%	25.8	10.2	-61%	44.5	24.3	-45%
Apartment 1 - 3rd f.	68.0	31.6	-53%	60.5	39.0	-36%	59.7	19.4	-67%	45.8	23.5	-49%
Apartment 2 - 3rd f.	62.0	29.2	-53%	60.5	39.0	-36%	48.2	15.3	-68%	48.0	24.8	-48%
Apartment 3 - 3rd f.	62.0	29.2	-53%	60.5	39.0	-36%	48.2	15.3	-68%	48.0	24.8	-48%
Apartment 4 - 3rd f.	70.6	32.7	-54%	63.2	40.2	-36%	59.4	19.6	-67%	51.6	26.0	-50%
Building	59.4	28.3	-52%	55.1	37.1	-33%	44.8	14.0	-69%	41.0	22.7	-45%

4.2. Installation of a condensing boiler and improvement in distribution system

In addition to the interventions to building envelope, thermal insulation it has been suggested an essential improvement of HVAC system to take full advantage of insulation measures. So doing, the introduction of a gas condensing boiler along with re-building the distribution system, since the current one has reached the end of lifespan, is associated to a temperature regulation and thermostatic valves attached to all radiators.

The building envelope interventions allow to significantly reduce the thermal loads of the project and, as a result, to continue using the existing radiators as heating terminals. Indeed, it is possible to maintain the same radiant surfaces, even with a lower operating temperature (45-40°C deliver and return temperatures) of the condensing boiler since the heat load was reduced by the insulation. With reference to the summer cooling, no completely new plant installation was hypothesized because the reduction of cooling loads implies the opportunity to maintain the heat pumps. Yet, to recover the original state of the facades, it is suggested to locate on the roof all the outdoor units of the existing air conditioners.

In this way, the HVAC system average seasonal efficiency is much higher than the previous one, i.e. 89.1% vs. 46.3%. Consequently, the primary energy demand for heating decreases appreciably from 101.7 to 15.7 kWh/m^{2}y with a reduction of 85 %. It is remarkable that the share of renewable energy is still zero in this configuration. Nevertheless, according the current energy classification in Italy, the building energy label reaches class A1.

From an economic point of view, the investment required for the replacement of plant systems is approximately 26,000 Euros. This value was estimated by assuming a parametric cost of 100 €/kW for the condensing boiler, another one equal to 15 €/m^2 for remaking the distribution system, 6 €/m^2 for the adjustment system and 10 €/m^2 for heating terminals. To sum up, when interventions on building envelope were included, the total cost is about 161,000 euro. Furthermore, the new price for gas supply can be estimated around 2,600 €/year, with a saving of 3.700 €/year compared to the status quo. Accounting for the 65% tax deduction applied in Italy for such interventions, the payback period can be estimated in 15 years.

4.3. Heat pump installation, improvement in distribution system and PV array integration

Another option to integrate a renewable share in the buildings is the installation of air-water heat pump along with storage facilities plus the previous measures on the building envelope. A PV array in amorphous siliceous around 6 kW of power can be in-stalled on the roof. A drawback of this configuration is that an increase of 50% in terminals surface must be taken into account since the heating is supplied at lower temperature by thermal storage (35-30°C deliver and return temperatures). Recent research demonstrated that, if available a high renewable electricity excess, by means of Power to Gas it is possible to green the high temperature heating supply [20,21].

Yet, limited available roof surface entail a lower temperature solution by means of heat pumps. In order to have a small size heat pump, a thermal storage of 8,000 liters was added to the system layout. The size of the thermal storage is designed to supply heat for 8 hours to the building during a typical day in January, the coldest month in Rome (charging temperature around 45°C). Furthermore, by the storage use it is possible to use the electricity from the Grid to feed the heat pump when the price of electricity is more convenient [22] or local renewables guarantee an energy excess [23].

This entails a further saving in terms of expenses. The average seasonal efficiency of this layout is 66.7%, asking for a primary energy consumption for heating equal to 31.3 kWh/m^2y, 70% less than the status quo. However, 64.6% of the primary energy demand can be met by renewable production. So doing, the non-renewable primary energy demand for heating is 11.1 kWh/m^2y. According the current energy classification in Italy, the building energy label reaches class A4.

From an economic point of view, the associated investment is equal to 42,000 €. To estimate this value, it was assumed a parametric cost of 250 €/kW for the heat pump, 1,500 €/kW for the PV array, 15 €/m^2 for the distribution system, 6 €/m^2 for the regulation devices and 15 €/m^2 for the heating terminals. To sum up, when interventions on building envelope were included, the total cost is about 187,000 €.

The cost of electricity for feeding the heat pump is about 700 €/year, with a saving of 5,600 €/anno compared to expenses for the gas supply.

Accounting for the 65% tax deduction applied in Italy for such interventions, the payback period can be estimated in 11 years.

5. Conclusions

The two phases of this research are closely connected each other, not requiring cut-ting-edge technology [24] but using economically viable solutions, already well-established on the market. The analytical step determined what are the strengths, weak-nesses and significant elements of the project. Then, in the second phase, assuming the possible interventions for the energy refurbishment, the preservation of architectural values is considered crucial.

Borgata Trullo, as typical public housing, shows great opportunity for reducing energy demand. It leads to consider relevant a first stage of survey to consider the nature of structural, conservative, social, managerial issues at the same time with the ones related to energy efficiency. The proposed design choices aim at improving the energy performance of buildings and to increase the comfort of the inhabitants but, by preserving the historicized aspect of the buildings. The values recognized as historical ones are fundamental evidence of a recent but important phase of Italian and European architecture history by its formal, structural characteristics and distribution of the artefacts.

The result shows the feasibility of energy efficiency measures and the opportunity to achieve high targets since the existing building stock has poor thermal performance. An important issue, often not considered, is the heating supply temperature in order to involve the existing distribution system or the terminals in providing the best performance with the foreseeable technological solutions.

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