Multi-Actor Urban Energy Planning Support: Building refurbishment & Building-integrated Solar PV

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Abstract

Considering the large amount of energy consumption in cities, two-thirds of the overall consumption, these latter have an important potential in terms of CO2 emissions reduction. Therefore, energy strategies are needed at a city level and consequently, adequate planning tools are required to support urban energy planners assess their decisions (e.g. which buildings are the best to refurbish). This paper presents an ontology based approach for urban energy planning support applied to building refurbishment and building-integrated solar PV planning. The adopted methodology is an iterative, incremental process, where each iteration leads to the integration of a new planning decision. The process starts by the identification of the actors whose interests are affected by the decision, then developing/ re-using computation models that provide answers for their questions. The different models are integrated using an ontology that models the parts of the city within the scope of the questions to be answered. The system is applied in a district (about 1200 buildings) in the city of Vienna. The adopted approach provides different actors with specific information to their points of view. Furthermore, the output is aggregated to a common level of abstraction, to be understood by all the actors. This approach is applicable to different cities, as the ontology also integrates extension and upgrade mechanisms that provide flexibility to cope with different data-availability contexts.

1. Introduction

More than two-thirds of primary energy in the world is consumed in urban settlements [1]. This energy consumption results in approximately 71% of all energy-related direct greenhouse gas (GHG) emissions [2]. Therefore, cities represent a rich ground for taking action to reduce the amount of GHG emissions. Therefore, decision makers, namely city administrations and governments, are developing strategies for energy planning at various spatial scales that clearly state what measures to be taken, where and in what quantities and in which time horizons.

However, cities are complex systems regarding the amount of components and interactions they comprise. The components the city covers can be: (i) physical components, such as buildings, streets, facilities, etc. (ii) human components, whose interests are to be considered or even (iii) regulations and laws that regulate the city. All these components, as well as their interactions, are to be taken into consideration by the decision makers in order to develop energy strategies. Moreover, these energy strategies have to be integrated, considering the impact of each decision on other decisions, besides their impact on the city.

To cope with the complexity of cities, adequate planning support systems are needed to formalize this complexity and automate the interactions that cannot be handled manually, by urban energy planners.

A large variety of tools exist already and they address different aspects of energy planning with a variance of scopes and fields of interest. A more comprehensive list is defined in [3]. However, in this paper, we focus on tools that have a comparable scope to the one of this work i.e. supporting

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energy planners in developing energy strategies. Such tools include, EnerGis [4] that aims to calculates the minimum annual heat demands of buildings within a geo-referenced context. SUNtool [5] and its later successor CitySim [6] are more on the energy simulation side and attempt to model and simulate energy flows of buildings, considering the individual properties of each building. SynCity [7] is considered as a scenario development, simulation, and optimization tool, at city level. It focuses on urban energy systems and it attempts to discover where large reductions of energy intensity can be achieved within the city. UrbanSim [8][9] is an open source framework that allows constructing scenarios and simulations that can be used at a city scale. It has GIS interface and addresses not only energy in the city but also other aspects. CommunityViz [10] is a scenario development and decision support tool for land-use planning. It is has a GIS interface and offers simple wizards to create different scenarios of land-use as well as calculations of different user-defined indicators. It is an extensions of the GIS software ArcGIS [11]. Semergy [12] supports decision making concerning building refurbishment. It offers a simple interface to users to define and optimize the best building configuration, in terms of refurbishment components, considering both energy efficiency and cost.

The above tools fill specific gaps in urban energy planning that they have been designed for. However, there are four main objectives that have been set in this research that they do not fulfill all together. These four main objectives are actually necessary conditions for urban energy planning support that we describe in the next section.

This paper presents an ontology-based approach for urban energy planning support. The ontology comprises information and knowledge to support an urban energy planning process that deals with both solar PV and building refurbishment planning, answering questions such as: what locations are the best to install solar PV systems or to refurbish for better thermal insulation. The proposed approach considers the multiple perspectives of all the stakeholders that are involved in the planning and decision making process.

2. Objectives

The objectives that are set represent the necessary conditions in urban energy planning support systems that have been defined in a previous related work[13]. They are mainly based on the analysis of an energy planning process and a data availability analysis in different cities.

The sustainable energy action plan (SEAP) process [14] is used as a reference process in urban energy planning, with more than 5000 cities and municipalities as users [15]. A data availability analysi was performed in a previous related work [13] in the cities of Vienna, Linz, Amstetten in Austria and Nanchang in China, in the context of smart city projects [16], where data has been collected to develop energy strategies for the respective cities. The following conclusion applied: (i) the more detailed data is, the les available it becomes. (ii) The level-of-detail (LOD) of available data significantly impacts the precision of the developed energy strategies. (iii) Data availability and LODs of data are significantly different, varying from a city to another.

The resulting conditions in urban energy planning support software are defined as the following:

1) **Supporting the perspectives of different actors**: the decision making process must involve all the stakeholders that have potentially affected interests and provide them with specific information, from their different perspectives.
2) **Shared understanding and quantifiable impact of decisions**: the assessment of the impact of energy strategies must be quantifiable. The output results must be aggregated to a level of abstraction that is understandable by all the different actors (i.e. stakeholders).
3) **Measures integration and resources negotiation**: the assessment of the impact of energy strategies must consider the interdependencies between different components and calculations

e.g. installing solar PV reduces the surface areas where solar thermal collectors can be installed.

4) **System viability through robustness against data availability problems**: The system must be flexible to be used within different conditions of data availability and levels of detail.

We note that these objectives have been used also as an assessment basis for the state-of-the-art tools that we have listed in the previous section.

3. Methodology and application

The presented methodology in this section is based on a general framework (met-methodology), the design science in information systems research [17]. This framework sets guidelines that have to be considered within the research process. These guidelines have all been explicitly or implicitly addressed by the adopted methodology.

The methodology is presented in this section with a running application of each of its steps, in modelling solar PV planning in a district in the city of Vienna (about 1200 buildings).

The methodology is an iterative incremental process, as shown in Figure 1, where each iteration starts by the scoping phase. In this specific work, this process has been run twice: once for considering solar PV planning, then another time for building refurbishment.

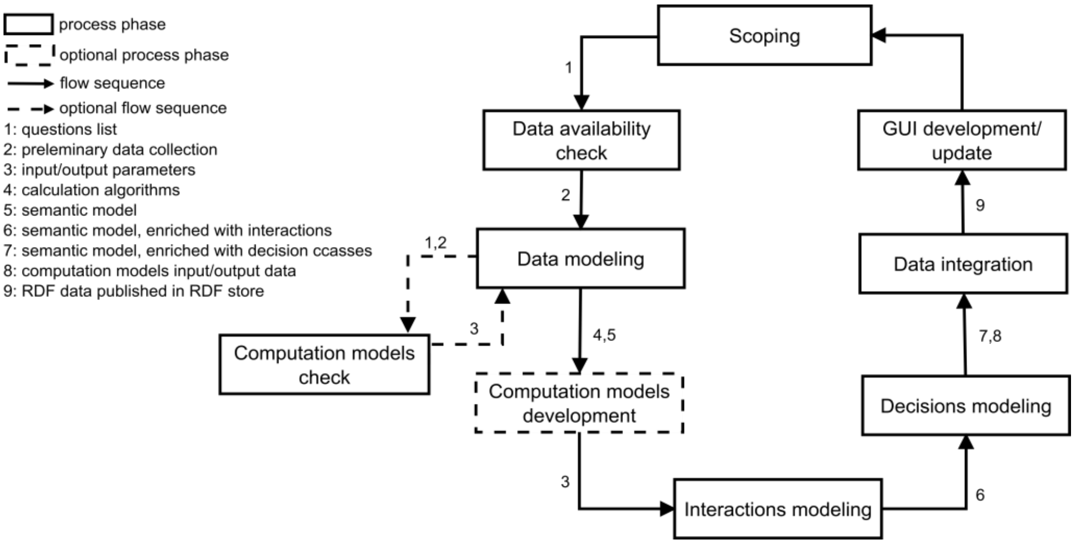


Figure 1: Main phases of the development methodology

Scoping phase, the actors (stakeholders) that are involved in the decision making process are identified. Then, for each actor, a list of questions that are of interest is established followed by a breakdown of the questions to a set of quantifiable expected answers, as shown in Table 1.

Actor	Question
Building owner	-What is the net present value of my investment? -What is my investment Break-even duration? -How much investment costs are required?
City Administration	-How much subsidies are to be paid to PV installations? -How much electricity is produced from subsidized PV installation? -How much CO2 emissions are saved with subsidized PV installations? -What is the CO2-emissions-saved-equivalent in terms of trees carbon sequestering?
Grid operator	-What transformers are overloaded because of PV installations? -What is the peak feed-in power at the transformers? -How long does the overload occur? -What is the electricity feed in Quantity? -How much is the direct use of the generated electricity?

Table 1: competency questions of the ontology-Solar PV planning

Data availability check: it is performed to understand what datasets exist and what their levels of detail are. The data availability (and un-availability) significantly impacts the rest of the process i.e. it is possible that some of the questions formulated in the scoping phase have answers of a low LOD.

The main information provider in this case was the city of Vienna. An initial data collection has been performed and it included a solar cadaster of the city [18], building stock data, standard electricity demand profiles, demographic data, solar PV funding schemes, etc. In brief, the acquired data was not detailed enough to aim at going in the direction of simulations but rather in making assumptions and generalizations, such as assuming that all residential buildings have the same electricity demand profile and correcting this assumption by using a diversity factor [19] where it is necessary.

Computation models check / data modelling: for each expected answer, in alignment with the available data, calculation methods are defined, by domain experts, listing all the intermediary steps. Then, semantics extraction is performed based on calculation methods, questions, expected answers, and actors. Then an ontology is developed as described in [20]. In the case that existing computation models can be reused, the data modeling phase considers the input and output parameters of these models as a basis for the semantics extraction and classification.

The final outcome represents an ontology of an urban energy system (UES), that includes concepts regarding solar PV planning and that is open to include more measures, and therefore making the UES be more and more general. The example in **Error! Reference source not found.** shows a fragment of the concepts of the UES, which deals with solar PV planning and that will grow later on to include more concepts the more measures are integrated.

Computation models development: computation models are developed (if no existing ones can be re-used) according to the calculation methods that have been identified in the data modeling phase, by domain experts. There are no restrictions in this phase on which programming languages or technologies to use.

For solar PV planning, Java computation models have been developed, while their data management has been performed by MySQL, PostGIS, and PostgreSQL databases. We note that some data preparation tasks have been performed in spreadsheets. The goal of the computation models is to calculate answers for the questions that are listed in the scoping phase.

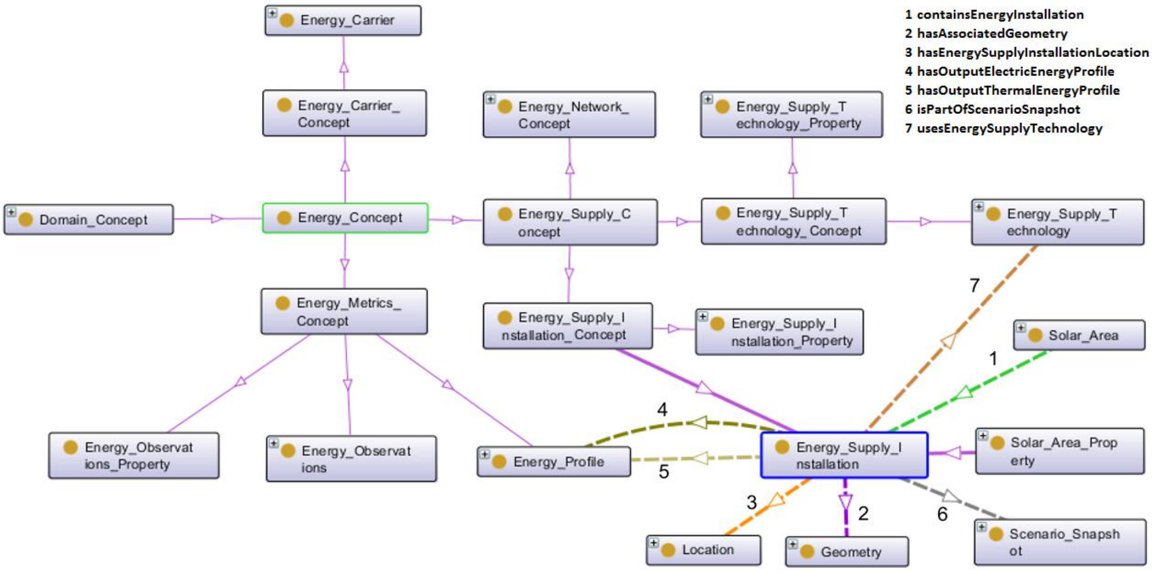


Figure 2: Ontology fragment- main solar PV planning concepts

Interaction modeling: in this phase, we capture the interactions between the different modeled components, showing which components are affecting which others through which data properties, as shown in Figure 3. The main goal of this phase is to keep the different calculation models integrated. In other words, it adds a part to the ontology so that it becomes aware about how every calculation model influences the others.

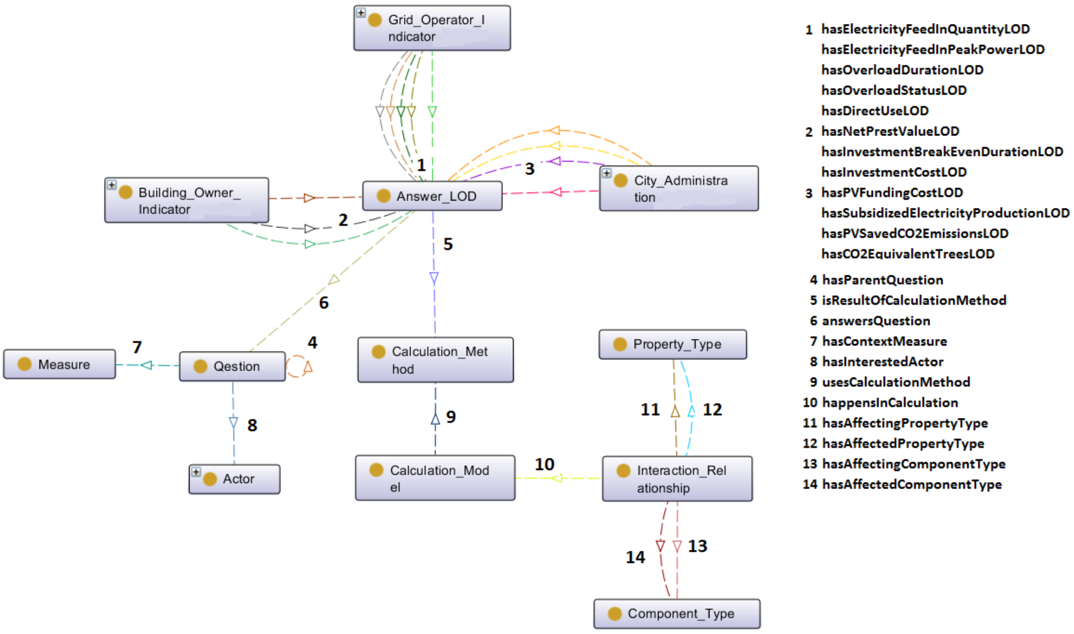


Figure 3: Ontology fragment- interactions of computation models

Decision modeling: in this phase, the knowledge of the actors regarding their interpretations of the values of the expected answers is captured. Rules are formalized to classify buildings (or groups of buildings) as having high or medium potential from each actor´s perspective. Then more rules are formalized to classify buildings as having high or medium potential for all the actors together. For example, a building is interpreted as having a very good potential for solar PV, by the building owner if the net present value of the investment is higher than 25000€. From a multi-actor perspective, it is considered as having very good potential for solar PV, if it does not overload the transformer within the low voltage grid and it has very good potential from one of the perspectives of the building owner or city administration.

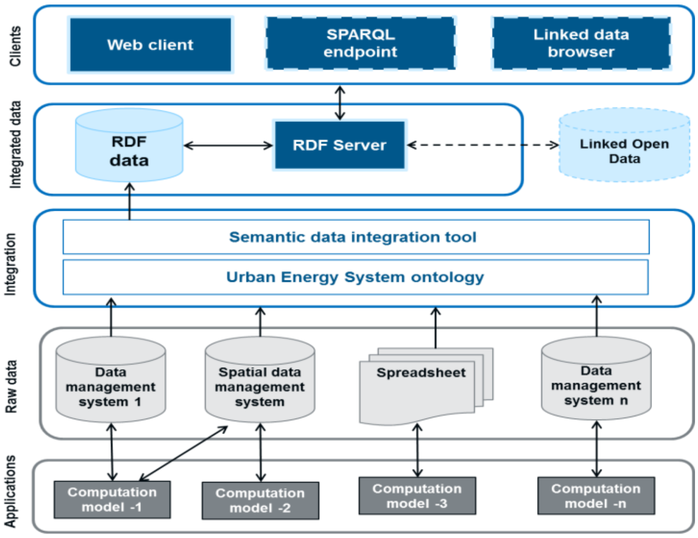
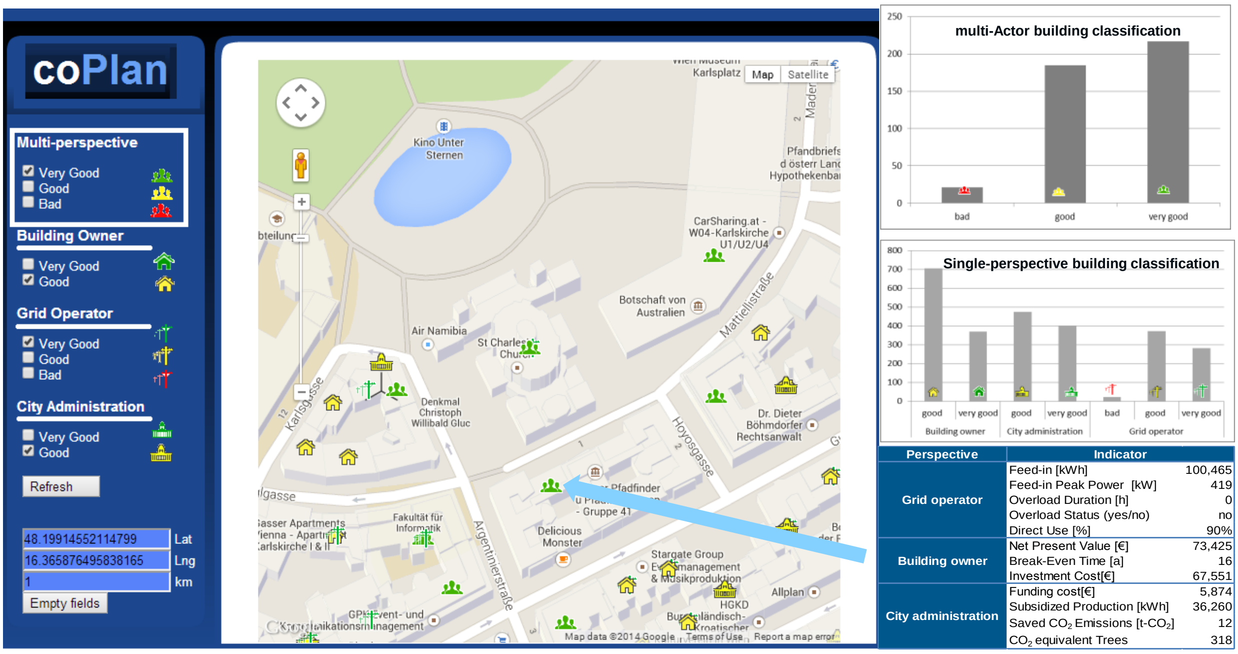


Figure 4: data integration architecture

Data integration: in this phase, the ontology is populated by data from the databases (or possibly spreadsheets) of the different computation models that have been used, using an existing data integration tool, Karma [21]. The integrated data are then served in a Resource Description Framework (RDF) format [22], as depicted in Figure 4.

GUI development: a light web interface is developed according to the workflow that energy planners prefer to adopt. The interface uses google maps to display the RDF data in a geo-referenced context. It is possible as well that the data are accessed through a SPARQL endpoint or a linked data browser. A sample preview of a potential interface is show in Figure 5.

The GUI development is still under progress and open for discussion with energy planners/urban planners: how to present the integrated data and under which workflow, or maybe even in a decentralized participative way, where different stakeholder are involved and all having access to the interface.



Multi-perspective
☑ Very Good
☐ Good
☐ Bad

Building Owner
☐ Very Good
☑ Good

Grid Operator
☑ Very Good
☐ Good
☐ Bad

City Administration
☐ Very Good
☑ Good

48.19914552114799	Lat
16.365876495838165	Lng
1	km

Perspective	Indicator	
Grid operator	Feed-in [kWh]	100,465
	Feed-in Peak Power [kW]	419
	Overload Duration [h]	0
	Overload Status (yes/no)	no
	Direct Use [%]	90%
Building owner	Net Present Value [€]	73,425
	Break-Even Time [a]	16
	Investment Cost[€]	67,551
City administration	Funding cost[€]	5,874
	Subsidized Production [kWh]	36,260
	Saved CO_2 Emissions [t-CO_2]	12
	CO_2 equivalent Trees	318

Figure 5: Sample interface preview

4. Building refurbishment planning integration

Similarly applying the same methodology as above, building refurbishment planning has also been modelled. The different stakeholders and their respective questions (which are answered by the ontology) are shown in Table 2. Given the LOD of the available data in building refurbishment planning, it was only possible to model at a census level instead of having more dtailed calculations at single buildings level as it was the case in solar PV planning. Thus, computation models have been developed based on the number of square meters per census and their distribution in terms of percentages over different building-uses and used-heating technologies.

Actor	Question
Building owner	-What is the net present value of my investment? -What is my investment Break-even duration? -How much investment costs are required?
City Administration	-How much subsidies are to be paid to refurbish buildings? -How much energy is saved by subsidizing building refurbishment? -How much CO2 emissions are saved by subsidizing building refurbishment? -What is the CO2 emissions-saved-equivalent in terms of carbon sequestering by trees?

Table 2: competency questions of the ontology-Building refurbishment planning

The integration of building refurbishment planning with solar PV planning was ensured through: (a) the integration of their data, by sharing the same ontology that represents an UES that contains concepts that are part of solar PV and building refurbishment planning. (b) Ensuring the consistency of data that are shared and calculated by the different heterogeneous computation models. This is achieved in the interactions modelling phase: the output data parameters of the building refurbishment computation models were checked if they are shared as input data parameters in the solar PV planning computation models and vice versa. As the building refurbishment involves data that are more related to thermal energy while solar PV models rather deal with electric energy, no interactions have been detected. Therefore no interaction-protocols were necessary to be modelled. (c) Integration of decisions of the different actors about the same locations in terms of their suitability for solar PV installation or building refurbishment. Since the LOD of the building refurbishment modeling was at a census (group of buildings) level, the solar PV planning data were also aggregated to the census level. Then, decisions about the integrated suitability in terms of solar PV or building refurbishment were modelled from different perspectives. E.g. from a building owner perspective, a census is more suitable for building refurbishment if the net present value (NPV) of this investment is greater than the NPV of a solar PV investment.

5. Conclusion

The developed ontology answers questions that different stakeholders raise to understand how their different interests are affected by the potential implementation of an energy strategy (i.e. stating which locations to use for solar PV or building refurbishment). The questions that the ontology provides answers for are listed in Table 1 and Table 2. The ontology is validated through its application within a district (about 1200 buildings) in the city of Vienna.

All answers are geo-referenced i.e. each location is related to a set of answers. Concerning building-integrated solar PV, the answers are available at each single buildings level, however for building refurbishment, given the current data availability, answers are related to groups of buildings. Therefore, the integrated assessment of building refurbishment with solar PV was possible only at the group of buildings level.

The developed ontology fulfills the four conditions of urban energy planning support [13] that have been set as objectives for this work. (1) Different stakeholders are provided with specific answers to their particular concerns, as shown in Table 1 and Table 2. (2) The answers that are provided are then summarized at each location (building or group of buildings) level, as very good, good, or bad locations, from the perspectives of each actor, then again as very good, good, or bad locations from all the perspectives together. (3) As explained in the methodology section, components interactions are captured, and integrated in the ontology, allowing the possibility to check data consistency and the integration of different computation models and planning decisions. (4) The development methodology allows the flexibility in calculating each single answer in more than one level of detail, using different calculation models e.g. if more detailed data are available about a given share of the city, more detailed models can be used for these, while the rest is calculated using more general models that do not require detailed datasets. Mechanisms of integrating multiple levels of detail data are formalized and integrated within the ontology.

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