Which is the optimum option for parking in the city centre?

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Abstract. Most contemporary Greek cities face the lack of adequate public space. This lack has a direct effect on parking space issues, turning cities’ open spaces into congested ones with parked cars. Although, according to Greek buildings’ regulations parking space must be provided within the building itself, especially in the county of Attica, where Athens, the capital, is located, the Law offers the possibility of exemption from this obligation in small building lots. Thus, in many cases, for small apartment buildings no parking space is provided within the building, forcing drivers to resort to either off-street parking or parking lots. Off-street parking may cause more traffic jams, noise and loss of time, among other negative effects, while parking lots have turned into environmental catastrophes in many cases (Soup, 2017; Davis et al, 2010). On the other hand, the construction of a basement parking space is linked with high initial costs, while parking spaces on other floors deprive vital area from living spaces, let alone the embodied energy of constructing these spaces. In this paper Life Cycle Analysis and Multicriteria Analysis is made so as to compare which the most sustainable option is; the creation of underground and ground floor level parking spaces within a small apartment building, off-street parking or the creation of a parking lot to host these vehicles. The environmental, social and economic effects of these three cases are analysed, taking into consideration both their constructional and operational effects. A comparison is made between these three options, with criteria for environmental protection, social equity and economic growth, the three pillars of sustainability, selected from relevant indicators of sustainable development. Hierarchy of the three examined options (off-street, in a parking lot or within the building parking) is made with Multicriteria Analysis. Through this research conclusions are drawn on the policy that cities should follow, so as to face in the most sustainable way the demand for parking space and whether legislation should change in regards to the provision of parking spaces within small building lots.

1. Introduction

Not so much research exists to contribute to the knowledge on the effects of parking infrastructure on energy demand, the environment, and the social cost of vehicle travel (Chester et al, 2010). Cars can either be parked on-street (by the pavement), in parking lots or in garages. As all these spaces occupy either public, open space or interior, private space, in buildings, parking is not only a transportation issue, but also an urban and building one.

It has been noted by several researchers (Chester et al, 2011; Soup, 2017; Davis et al, 2010) that free parking (either on-street or in parking lots) encourages solo driving, hence discouraging more environmental-friendly and healthier transits, such as walking, biking or the use of public transit, while it greatly contributes to urban congestion. On-street parking has been found responsible for large
amounts of energy waste, carbon dioxide emissions, contribution to congested traffic, as well as time waste. According to Soup (2017), 30% of cars in congested traffic in USA cities try to find on-street parking. More specifically, 45% of the total traffic volume in Brooklyn and 26% in Manhattan cruise for a parking space (Sykes et al, 2010, cited in Spiliopoulou and Antoniou, 2012). Regarding the time spent cruising for on-street parking, it depends on many parking-related variables, such as parking capacity, occupancy ratio, turnover rate and place fee (Belloche, 2015). According to Soup (2017), British drivers spend an average of 25 minutes daily in order to find an on-street parking place. Belloche (2015) has reported an average cruising time of 20 minutes in Lyon, while Ćuljković (2018) has reported an average of 7.3 minutes in Belgrade, causing excess consumption of 46.7lt of fuel, 178kg CO₂ and 789km total distance by 598 vehicles daily. It has been found out that the average time to find an on-street parking space in the Upper West Side of Manhattan is 3.1 minutes and the average cruising distance 0.37 miles (Soup, 2017). According to these findings, the few blocks investigated in the survey, cause approximately 366,000 excess vehicle miles of travel and are responsible for 325 tons of carbon dioxide emissions annually (ibid). Searching for parking increases fuel consumption, not only because of the distance that has to be made, but also because vehicles start moving at a slower speed; Benenson et al (2008) found out that generally car speed is reduced to 20–25 km/h when drivers begin to estimate the conditions of parking in a zone, and further to 10–12 km/h when they start looking for a parking space. Carbon dioxide emissions from a vehicle rise with speed increase or decrease (Ecodriven, 2008).

Davis et al (2010) have concluded that surface parking lots consume large amounts of urban space, reduce ecosystem services and contribute toward runoff and pollutants. Apart from that, they undermine walkability (Shoup, 2017), can lower land values (Wilson, 1995) and are generally considered to be unattractive and sometimes hostile places (Gibbons, 1999). Shoup (2017) characterises them as environmental and ‘poleodomogenic’ catastrophes for many USA cities.

On the other hand, the creation of buildings has been linked with high maintenance, operational and embodied energy consumption (Syngros et al, 2017), as well as with large raw materials consumption (Dimoudi and Tompa, 2008) and significant environmental footprint (Burge, 2009), depending on the materials, techniques used as well as on the design and the building lot. Garage buildings or parts of buildings that are designed for parking cannot be an exception, although significant research has been made to suggest their environmental improvement (Walach et al, 2017).

As vehicles spend most of their lives parked (Chester et al, 2011), parking becomes a major part of both transportation and land use (Shoup, 2017), preventing alternative land uses (Marsden, 2014), also having a direct effect on the urban landscape. It is thus important to investigate the environmental, energy, social and economic effects of the options for hosting parked vehicles in the urban environment, where the lack of space is crucial for any activities occurring there. It is also crucial to examine whether existing legislation promotes the most sustainable systems for parking or not. Most of research on parking focuses on the effect of parking policies and mostly on pricing parking spaces on their availability (Soup, 2017; Thanh and Friedrich, 2017; Mingardo et al, 2015), on driver’s choices (Kobus et al, 2013), on how parking policies affect sustainable mobility (Soup, 2017; Migliore et al, 2014; Antonson et al, 2017) or on carbon dioxide emissions from cruising (Ćuljković, 2018) as well as on time cruising for parking and egress time from the parking space to the destination (Yan et al, 2019; Thanh and Friedrich, 2017), concentrating mostly either on parking lots or on-street parking and their effects on the aforementioned parameters and not on the comparison of the three available types of parking.

The aim of this study is to underline the optimum type of parking practice, from a sustainability point of view, focusing on the three pillars of sustainability (environmental protection, social equity and economic growth (UN, 1987)) and to highlight the essential improvements in existing legislation so as to achieve sustainable parking practices in Greek city centres. For this reason, the nomenclature proposed by Chester et al (2010) is followed; three primary groupings of parking are assumed and examined: on-street (within a road’s right-of-way), surface parking lots (built directly on land), and structure (within a building structure, generally known as ‘garages’).
2. Case-study, Assumptions, Methodology

Legislation in Greece promotes the creation of parking spaces within buildings, however with some exemptions. According to Presidential Decree on *Determining the necessary number of parking spaces of cars depending on the use and the size of buildings on the continental section of Attica county and abolition of P.D. 230/1993(A’94)* (2004) for residencies within the county of Attica, where Athens belongs, one parking space should be provided within the building for each 100m² of residency and at least one parking space per apartment. However, the Law on *New Construction Regulation* (2012), for building lots less than 300m² allows for the redemption of parking spaces which ‘are not ensured by the study’. The amount of this redemption was first established by the Law on the enforcement of obligations for the creation of parking spaces of cars for the service of buildings and regulations on related issues (1979) and was updated by the Decree on the Procedure of certification and collection of redemption according to article 5 of l960/1979 (1980). As the phrase ‘not ensured by the study’ allows for large interpretations, very often in practice, most owners of building lots of 300m² or less insist on the option of the redemption than of allowing for more parking spaces1, which would result in sacrificing residential space, which can be sold at a higher price than parking space.

So as to examine whether sacrificing parking spaces within a building is a ‘sustainable’ measure, a 300m² building lot is assumed in the city centre, in the area of Exarchia (Figure 1), with a floor area ratio 3.6². It is interesting to mention that the maximum capacity of on-street parking³ occupies 8.85% of the total area, while green spaces only 12.97%. There are some small parking lots, which occupy 0.84% of the total area.

According to the restrictions of Law on *New Construction Regulation* (2012), 12 apartments of 70m² each can be made on the ground floor and the upper floors of the examined 300m² building lot, without the creation of parking spaces within the building. For the creation of parking spaces within the building, 11 apartments can be made (one on the ground floor and the rest on the upper floors), with 3 parking spaces allocated on the ground floor and 8 in the basement that is constructed for hosting parking spaces for all 11 apartments (one per apartment, according to Presidential Decree on *Determining the necessary number of parking spaces of cars depending on the use and the size of buildings on the continental section of Attica county and abolition of P.D. 230/1993(A’94)* (2004)).

Three scenarios are examined for this building lot:

| Scenario 1: No parking space within the building – the inhabitants of the 12 apartments park their vehicles on-street, having paid the respective redemption for 12 parking spaces. |
| Scenario 2: No parking space within the building – the inhabitants of the 12 apartments park their vehicles on a surface parking lot. As there is no space available for a new parking lot in the area, the parking lot to accommodate these cars, replaces 300m² of an existing urban park (one of the few available public spaces in the area). In this case, the redemption of 12 parking spaces has also been taken into consideration. |
| Scenario 3: Parking space is made on the building’s basement and on its ground floor (giving the building a suspended form on pillars), where the vehicles of the inhabitants of the 11 apartments are parked. |

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¹Personal communication with architects employed in the Buildings Permit Service in the Municipality of Athens. The argument that ‘it is more environmental friendly to ask for redemption for parking spaces than to build underground garages’ is often used by owners or their architects, without any scientific justification.

²Information derived from the Buildings Permit Service of the Municipality of Athens.

³Although occupation of pavements and pedestrian streets by parked vehicles is very strong and seems an acceptable behaviour, it has not been taken into consideration in the estimation of the maximum capacity for on-street parking.
Figure 1. Boundaries of case-study area

It is assumed that dwellers use their cars every working day to and from work, on Saturdays for shopping and on Sundays for promenades / excursions, 50 weeks per year. Although travelling behaviour is significantly affected by parking availability (Christiansen et al, 2017), for reasons of direct comparison, the same travelling activities are considered statically for all scenarios. For these activities, the effect of parking in the vicinity of home is considered, as it is the only differentiation in the use of the vehicle among the examined scenarios. In Scenarios 1 and 2, twelve cars are considered (one for each apartment), while in Scenario 3, eleven cars are considered (again, one for each apartment).

The surface parking lot of Scenario 2 is made of asphalt, on C16/20 reinforced concrete, equipped with street lighting and rainwater sewage systems, while the underground parking space within the building of Scenario 3 is made of reinforced concrete C20/25, covered with industrial flooring and plastered vertical surfaces, equipped with lighting and metal garage doors.

The operational energy consumption for the non-heated parking space within the building, as well as for the surface parking lot is considered to be only for lighting, with LED lights; an average 6 hours per day artificial lighting use is considered in Scenario 3 and 12 hours per day in Scenario 2. No electric vehicles chargers have been taken into consideration in any of the scenarios. The operation of all three scenarios is considered to be 60 years.

2.1. Choice of Criteria and Estimation of Indicators

So as to investigate which the most ‘sustainable’ scenario is, environmental, social and economic criteria have been chosen, from the three pillars of sustainable development (United Nations, 1987). There is a plethora of work on which the criteria of sustainability in the urban space should be (e.g. Olewiler, 2006; United Nations, 2007; Van de Kerk and Manuel, 2008; Shen et al, 2011). So as to assess the three aforementioned scenarios, the following 13 criteria are used (Figure 2): Regarding
environmental criteria, the basic 7 criteria used in Life Cycle Analysis are chosen: global warming potential, with the indicator of carbon dioxide equivalent, ozone depletion potential, with trichlorofluoromethane equivalent as its indicator, human health particulate, with fine particulate matter equivalent as indicator, smog potential with indicator, ozone equivalent, eutrophication potential uses nitrogen equivalent as indicator, while for acidification potential, sulfur dioxide equivalent is used. For the heat island effect, surface solar reflectance is used. Regarding energy savings, primary energy consumption is its indicator. On the subject of social criteria, the availability of local public green areas, as well as the urban landscape and the quality of life are chosen, with respective indicators the protection / potential of creation of green spaces, the negative effect of certain features on the urban landscape and the time spent on finding a parking place. Regarding economic criteria, expenditure is chosen, with indicator the initial cost of technical works, while for financial criteria, public revenue is chosen, with redemption as the indicator.

The environmental and energy indicators of these three scenarios are estimated with the Life Cycle Analysis software ATHENA Impact Estimator for Buildings, which has been used successfully in research and practice to assess the environmental effect of complex systems (O’Connor and Bowick, 2014; Haapio and Viitaniemi, 2008; Stek et al, 2011). For Scenario 2, the more specific for paved surfaces Life Cycle Analysis ATHENA Pavement LCA online web application is additionally used.

Due to the lack of recent available data on cruising for Athens, average cruising duration (t) in the examined area (Scenario 1) has been estimated from surveys with inhabitants and people who work in the area of Exarchia. People have been asked to estimate how much time they have to cruise for parking during the morning, afternoon, evening and night hours of workdays, Saturdays and Sundays. Fuel consumed for cruising (F – in Lt) is given by the relationship:

$$F = N \cdot q \cdot V \cdot t$$

Where N is the number of cruising cars, q is the specific fuel consumption of cars (Lt/km), V is average cruising velocity (assumed 11km/h, according to Ćuljković (2018)). Specific fuel consumption derives from the latest census of the European Environmental Agency. The latest available data is that the specific fuel consumption of an average car is 83.31Lt/km, while there is an approximately 99% annual reduction of specific fuel consumption (EEA, 2012). In order to take this
decline into consideration for the assumed 60 years, the fuel consumed for cruising is given by the formula:

\[
\sum_{i=1}^{60} F_i = F_1 \left( 1 + \sum_{i=1}^{59} 0.9^i \right)
\]

In all, from the answers of 20 inhabitants of Exarchia who commute by their privately owned car, an average cruising time of 12.9min has been found out, while this number becomes 14.8min during weekdays evenings, 16.4min on Saturday afternoons and 8.8min on Sunday evenings.

Through in situ observations, it has been noticed that the majority of parked vehicles is dark coloured. The solar reflectance of dark coloured cars is considered in Scenarios 1 and 2, higher than the one suggested for black cars by Levinson et al (2011), while a flat roof, covered with light-coloured cement slabs is considered in Scenario 3 (Androutsopoulos et al, 2017).

In order to quantify the qualitative criterion of urban landscape, experts have been asked to give a value from 1 to 5 on the negative effect of on-street parked cars, of a parking lot and of a suspended-on-pillars-type building on the urban landscape. 37 architects, engineers, urban planners, archaeologists, engaged in academia, the public and the private sector and have had large experience on the subject of the city of Athens and its landscape, have responded, giving an average value of 4.1 on on-street parked cars, 3.8 on parking lots and 2.9 on suspended buildings, regarding the negative effect of each case on the urban landscape.

The qualitative criterion of the protection of green spaces is quantified by the authors in a scale of 1 to 5, depending on the relationship of each scenario to the protection / potential of creation of green spaces. As Scenario 2 transforms a green space to a parking lot, the value ‘1’ is given to it. In Scenario 1, public space that could be potentially occupied by pocket parks or trees is used to accommodate on-street parked cars, that is why the value ‘3’ is given to it. Finally, to Scenario 3, where a building is constructed on a lot that has been destined to be constructed, ‘4’ is given, as it does not destroy existing green space, nor occupies a potentially green one, yet it does not protect neither creates green spaces.

The cost of each structure (Scenarios 2 and 3) is estimated according to the Regulation on the Descriptive works invoices for public works contracts (2017) and from market research.

Finally, the financial criterion of the redemption for Scenarios 1 and 2 is calculated according to the Law on the enforcement of obligations for the creation of parking spaces of cars for the service of buildings and regulations on related issues (1979) and its update (Decree on the Procedure of certification and collection of redemption according to article 5 of l960/1979 (1980)).

So as to establish which scenario is the most sustainable one, multicriteria analysis is used, a decision-making process which has been used in various sectors, from agriculture, environment, water management, transport to finance and human resources, among others (Zopounidis and Pardalos, 2010). More specifically, the Multi-Attribute Utility Theory (MAUT) is chosen, as it respects the axioms of comparability, reflexivity, transitivity of choices, continuity and dominance (Ishizaka and Nemery, 2013).

The significance (weighting factor) of each of the 13 criteria is examined for citizens through an online survey that took place from January to May 2019, to which 359 people have responded. The

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4 Some interviewees answered that it is an impossibility to find a parking space in the area on Saturday afternoons or on weekdays evenings, stating that they schedule their car commuting to avoid cruising during these periods or that they prefer to use taxi for this reason, instead of their own car. Many of the interviewees (beyond the 20 on whose answers, average cruising time has been estimated) stated that they park their cars either in privately owned garages or on their privately owned parking space in the building where they dwell, either for reasons of safety or because on-street parking had become an impossibility for them.

5 Although the authors believe that parking lots have a greater negative effect on the urban landscape than on-street parked cars, the average value suggested by experts is used in this research. As parking lots in the centre of Athens are small and scarce, it appears that they do not seem as catastrophic to Greek experts as to their American peers.
survey has been posted on social media, on celebrity web pages and has been sent through e-mail in order to ensure answers from a broad spectrum.

3. Results and Discussion
The results from the LCA analysis for the environmental and energy criteria and for the rest of the criteria are shown in Table 1. It is obvious from Table 1 that letting 12 cars cruise daily for parking is disastrous from an environmental point of view; in this case, carbon dioxide emissions equivalent is 1,600 times larger than for the construction and operation of a basement for hosting parked cars (Scenario 3) and 700 times larger than the construction and operation of a parking lot (Scenario 2). In all cases the environmental effect of cruising for on-street parking is more critical for cruising, followed by the creation and operation of a parking lot, while the creation and operation of an underground space has the smallest environmental impact for all seven environmental criteria examined. Similarly primary energy consumption for cruising is 2,000 times larger than the creation and operation of an underground space and 400 times larger than the creation and operation of a parking lot.

On the issue of the social criteria, the creation of an underground and suspended ground floor parking space has the smallest negative effect on the urban landscape, while on-street parking has the largest, according to experts. The replacement of a part of an urban park with a parking lot has the worst effect on the protection / creation of green spaces, while on-street parking has the most negative effect on the time spent for finding a parking space.

Table 1. Weighting factors for each criterion, estimated values of the indicators considered for each criterion (for 60 years), rating and ranking of each Scenario

| Scenario | Weighting factors | Indicator: | Units: | Rating (MAUT) | Ranking |
|----------|------------------|------------|--------|---------------|---------|
| 1        | 4.68 4.52 4.73 4.68 4.49 4.53 4.63 4.59 4.82 4.63 4.08 3.69 3.67 | Carbon dioxide equivalent | (tn CO2 eq) | | |
| 2        | | Trichlorofluoromethane equivalent | (g CFC-11 eq) | | |
| 3        | | Fine Particulate Matter equivalent | (tn PM2.5 eq) | | |
| 4        | | Ozone equivalent | (tn O3 eq) | | |
| 5        | | Nitrogen equivalent | (kg N eq) | | |
| 6        | | Sulfur dioxide equivalent | (kg SO2 eq) | | |
| 7        | | Surface solar reflectance | - | | |
| 8        | | Total Primary Energy Consumption | (TJ) | | |
| 9        | | Protection / creation of green spaces | [Scale: 1-5] | | |
| 10       | | Negative effect on the urban landscape | [Scale: 1-5] | | |
| 11       | | Time spent on finding a parking place | (min) | | |
| 12       | | Initial cost of technical works | (Euro) | | |
| 13       | | Redemp | (Euro) | | |

| Scenario 1 | 125,589 | 5.23 | 14,628 | 3,662 | 12,419 | 263,479 | 0.1 | 174 | 0.24 | 3 | 4.1 | 12.9 | | | 125,000 | 0.183 | 3rd |
| Scenario 2 | 183 | 0.23 | 167 | 10 | 35 | 1495 | 0.1 | 4.34 | 1 | 3.8 | 0 | 23,831 | 125,000 | 0.731 | 2nd |
| Scenario 3 | 76 | 1.01 | 91 | 6 | 54 | 393 | 0.6 | 0.87 | 4 | 2.9 | 0 | 34,377 | | | 0.860 | 1st |
Regarding economic criteria, the creation of the parking lot is less expensive than the creation of the underground garage. Concerning financial criteria, Scenarios 1 and 2 excel Scenario 3, as they produce public revenue, thanks to redemption. Although Scenario 3 ranks last in both the expenditure and public revenue criteria, it ranks first in the rest of the criteria.

The weighting factors with which these criteria are combined in MAUT analysis are also shown in Table 1. It is interesting to mention that environmental criteria have achieved the highest score, followed by social criteria, while economic criteria have been given observably the smallest scores. These scores reflect the fact that environmental issues have been of concern to the public opinion recently, while in Greece of austerity and mistrust to central authorities (Karageorgiou et al, 2017), it is natural that people do not highly estimate economic criteria related mostly to the state.

The calculated / estimated values of the indicators, combined with the weighting factors of each criterion, according to MAUT methodology, result in rating factors for each scenario, which lead to the ranking of each scenario, which can also be seen in Table 1. As is obvious, the creation of a garage within a building (Scenario 3) is the most sustainable solution. The parking lot (Scenario 2) is the second option, while letting cars cruise (Scenario 1) is the worst option. Other researchers have also concluded that parking inside a garage is the most sustainable option (Soup, 2017; Chester et al, 2010, Davies et al, 2010), without combining examined criteria, so as to assess a ranking to justify this argument.

In the finite and limited public space of Athens, the majority of whose building stock is not equipped with parking spaces, allowing newly constructed buildings not to provide for parking spaces is far away from achieving sustainable development. As the majority of lots which have not been built yet in the Municipality of Athens is less than 300m², allowing in force a 40-year-old law that permits to construct buildings on these lots without the provision of a parking space can only lead to larger environmental and social problems. Cars will either cruise for parking on-street (which will lead to more limited public space, less possibilities for green spaces, more time spent for cruising, with direct negative effects on the landscape, the society and the environment) or existing open, green spaces will have to be transformed into parking lots, again, with the environmental, city planning, social and landscape negative effects that these spaces cause.

4. Conclusions

About 250 years ago Thomas Paine (1776) famously wrote "time makes more converts than reason". This ‘conversion of reason’ that has occurred during the 20th century car domination of cities, on the issue of privately owned vehicles occupying public space and urban landscape abundantly must change, if we wish to evolve to sustainable cities and systems. The finite space of limited open spaces of city centres must accommodate people, activities for people of all ages, green spaces and not cars.

Through the comparison made in this study about accommodating the cars of the inhabitants of a new-built building on a small building lot and the sustainability criteria with which parking options have been examined, it is made clear that on-street parking is the most unsustainable option. Parking lots is also an unsustainable option, but with less appalling effects than on-street parking. The most sustainable option for the environment, the landscape and society is the creation of parking spaces within the building itself. Other criteria, which have been beyond the scope of this research, such as public safety in cases of earthquakes or fires make up for the necessity of dislocating cars from on-street parking, if we want our cities to be transformed into sustainable and resilient ones.

It is thus important to displace parked vehicles from public and open spaces and place them within buildings; for new buildings it should be mandatory that parking spaces are provided within the buildings themselves, without any exceptions. In the finite urban space of city centres, intelligent applications for finding a parking space or for car sharing, can only cure the symptom but not one of the causes. The forty year-old laws that allow for the exemption of garage spaces for small building lots should be abolished, if the Municipality of Athens and the Greek central government want to put

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6 Information derived from the Buildings Permit Service of the Municipality of Athens.
in practice the sustainability agenda they have announced (Skoula, 2017; Skoula and Myrivili, 2017) for the transformation of existing cities into sustainable ones.

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