bitCar

Design Concept for a Collapsible Stackable City Car

by Franco Vairani

Master of Science in Architecture Studies
Massachusetts Institute of Technology 2001

Diploma of Architect
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Submitted to the Department of Architecture in partial
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Problems associated with the massive adoption of automobiles have become the center of a world-wide debate. While new technologies will eventually discover a sustainable solution to the environmental concerns (pollution, depletion of energy sources), cities will continue struggling to accommodate the increasing number of cars. The ability for people to move quickly across large distances and the infrastructure required by the automobile (mainly roads and parking) have also created an unsustainable urban landscape in many countries. The argument of this work is that these problems are partly the result of an outdated set of design premises for the automobile which have not changed since it appeared in the late 1800's. A typical car is too big, too heavy, most of the times it only transports one person for a few miles, and then it remains unused for 95% of the time. These inefficiencies multiplied by the staggering number of vehicles in circulation have resulted in huge energy losses, pollution and vast portions of the city lost in support systems for the car. The work discussed here proposes a different approach to urban transportation, by combining the advantages of mass transit with the convenience of personal mobility. Instead of designing automobiles to fullfil any kind of travel need and additional parking structures destined to accommodate 85% of these automobiles, this work proposes a reconfiguration of the car based on the characteristics of the majority of vehicular urban travel. The design of the car operates on a shared-ownership model, with a collapsible structure that allows vehicles to contract and park in stacks. Based on the available data, results indicate that such a design could potentially reduce the actual space requirements for a car between 1/20th and 1/75th. The design of the car is complemented by the use of electric in-wheel motors, developed in connection with the Smart Cities group run at the MIT Media Laboratory under the supervision of Professor Mitchell, for additional efficiency, especially in terms of energy consumption.

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cross roads

urban transportation

People have clustered in cities since the Neolithic times, to gain more convenient access to people and resources that would otherwise be spread. Thus, accessibility is a fundamental quality of cities and transportation, in turn, becomes a key factor to obtain access to these resources. Cities depend on transportation links to connect people and goods to, from and within the city limits, so transportation methods always play a fundamental role in the shape of a city. However, when cities grow too large with too many people, an interesting paradox occurs. While larger

Fig. 1.1
Buenos Aires

cities offer more opportunities in quantity and quality than smaller ones, mobility for its citizens becomes increasingly challenging, thereby crippling accessibility to the resources the city has to offer. This process forces people to look elsewhere, or to re-arrange the built environment to better meet their needs. So the relationship between the transportation and the shape of the city is always directly related.

Transportation is almost always a means and not a destination, that is, they take people to their destination. The problem is, of course, that transportation systems also occupy real estate that could be available for other resources, such as housing, business establishments or recreational areas, thus creating a conflict. The more land destined to transportation systems, the less land available as destination points.

Mobility has been a constant necessity in human development. For ages, human settlements were small enough that most mobility demands were satisfied simply by walking. However, the limitations of human mobility are quite obvious, so even in early communities human ingenuity sought other ways to assist it. Live stock and the use of the wheel were soon put to use, making possible for people and goods to move more quickly and cover greater distances.

Naturally, this also leads to a constant reconfiguration of the human settlement itself. When faster means of transportation are available to its residents, the town or city can spread its resources over a larger area. This effect became particularly evident after the industrial revolution, when communities went from small-scale urban patterns to metropolitan areas with segregated zones for production and service zones. This transformation both required and was pushed by the utilization of newer transportation methods that could carry more people faster to and from these zones. Many scholars call this process the transition from the "walking city" to the "transit city" (Newman, Kenworthy 1999). Cities started growing outwards as the train and streetcars (first horse-drawn, then steam, then electric) allowed a large number of citizens to move quickly between distant zones. Almost at the same time, bicycles appeared on the scene and quickly became popular. Eventually, the invention of the internal combustion engine and its application on means of transportation would have a major impact on the configuration of the urban landscape.

Since transportation links are such a crucial component of any town or city, there are usually several alternatives for people to physically reach those geographically distributed resources. These systems can be broadly categorized into two important groups: public transportation and personal mobility.

Personal mobility

Personal mobility is a simple concept. It comprises all those methods that provide transportation to people on an individual basis.

Not considering walking, devices in this category take on demand [at least ideally] one person to the exact location where he/she wants to go, and that is their great advantage. Users do not need to accommodate their plans to constraints imposed by fellow citizens to get to their destination. They simply go where they want to go at the time that is most convenient for them.
The scale of devices used to assist in

personal mobility varies greatly, and so does their design depending on its purpose. While they all provide transportation, some devices are specifically targeted for recreation purposes, others for the young, the elderly, the handicapped, and many more. Some are depend on human power, some on animal power and others are artificially powered. Typically, these devices are privately owned, so the cost of acquiring one unit is absorbed directly by the end user.

In this category we find cars, of course, bicycles, tricycles, all-terrain quadricycles, motorcycles, scooters, mopeds, skates, skateboards, skate-scooters, roller skates, segways (TM), wheelchairs and several other contraptions that defy classification.

Public transportation

Public transportation or mass transit consists of all those systems that offer transportation services to the general population, such as trams, buses, subways, ferrys, trains, etc. They rely on large units with a shared space to move a group of individuals at the same time from one location to another. These services usually charge a set fee and run on a predetermined schedule and on a fixed route. This route is marked by designated stops, where people get on and off the transit system. Consequentially, these stops have to be carefully planned to coincide with more or less important places; that is, where most people are and where most people want to go. Most modern cities have some kind of implementation of public transit, to guarantee that at least the basic resources are accessible to everyone. In general terms, public transport requires some kind of infrastructure which sometimes can be substantial, such as terminals, tracks, elevated rail lines, tunnels, etc. Nevertheless, because these services are shared by a large group of citizens, the cost and value of mass transit can potentially be significantly lower than that of private transportation.

Also because these systems are shared by the entire population in a city, their services are usually regulated and sometimes run by the city's government.

Fig. 1.2

Light rail, subway and commuter rail lines in Boston, MA

Usually, personal mobility systems are seen as the opposite to mass transit. Personal mobility takes one individual directly to his/her destination so they need to be very flexible. On the other hand, transit moves a group of people only between predetermined points. While the efficiency of transit can be extremely high, these systems are not flexible in the service they provide. Unless the user is located exactly at one of the stop points and needs to go exactly to another stop point in the transit system, for most of the people, most of time, their trip needs to be complemented by some other means that bridges the gap between the transit stop and the origin of the trip as well as its final destination (graphic). Therefore, when city planners are designing a new transit system, they must take into account acceptable walking distances, connections to other transportation services, etc.

Walking

Walking is the basic means of mobility for humans. In small settlements as well as in communities with lower economic development, it is still the main method for accessing the resources of the city. But even in the most technologically advanced and rich urban areas, there is always a portion at the beginning and end of each trip that is carried out by foot. However, it is also true that the presence of assisted means of transportation has diminished the number of people who walk regularly for their daily activities. For example, in the US, the number of people who walk to work has declined steadily over the last few years (Fig 1.4). For hundreds of years, cities have been configured around pedestrian movement, but even today with the strong presence of the automobile, most urban plans include

Fig. 1.3
Pedestrian area in Salamanca, Spain

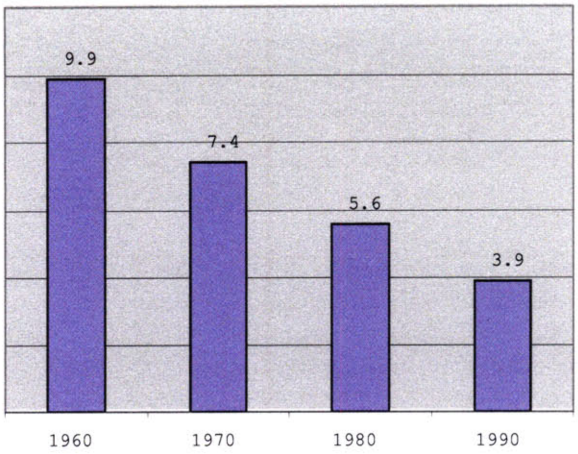


Fig. 1.4
Percentage of population who walk to work in the U.S. [1]

areas specifically for walking (sidewalks, walkways, piazzas, colonnades, pedestrian zones, crossings, bridges, etc). A recent, more extreme example of a public zone for pedestrian movement is in fact the shopping mall. Although they are usually located out of walking distance from residential zones and depend on the automobile to be reached, internally, shopping centers are secluded semi-public agglomerations of stores where pedestrians circulate freely without the getting in conflict with other means of transportation. Walking has clearly some benefits. It is very economical (minimal infrastructure), a healthy activity, and has no negative environmental impact. Of course, it also has some important shortcomings. For one, humans get tired of walking rather quickly, and movement by foot is fairly slow at about 3 to 4 mph (4.5 - 6.5 km/h). Things get a little more complicated when external factors come into play. For example, when the terrain is not flat and there are obstacles, people are more reluctant to walk or become tired more easily. Likewise, when there is the need of carrying goods from one point to another, walking becomes substantially more difficult. Adverse weather conditions may also affect or prevent pedestrians from reaching their destination.

Bicycles

People have sought ways to overcome the limitations of walking through the use of assisted means of transportation that would move them beyond their natural abilities. Bicycles appeared in the 19th century and still remain about the most energy-efficient method for transporting a single person. Bicycles are small and lightweight and a human on a bike can move a mile with 35

Fig. 1.5
Bicycles in Shanghai, China

calories, compared to 100 calories required for walking and about 1900 calories to move a car with one passenger. A healthy person on a bicycle can also achieve much higher speeds than walking (20-30 mph) which extends his/her accessibility area. Thanks to their reduced size and weight, they can be parked almost anywhere, providing transportation from point to point, on demand. Even more, because biking depends on human-power just like walking, it promotes a healthy activity and generates no air or noise pollution. These machines provide a very economic means of transportation since the required infrastructure is minimal and the additional calorie intake required to move on a bicycle has no significant economic impact. Plus, the initial investment (absorbed by the individual) is significantly low compared to an automobile.

However, a combination of factors have pushed a decline in the use of bikes in the US and other countries, mostly in favor of the automobile (see chapter 2) but it remains a popular means of urban transportation in many countries in Europe (especially in Holland and Denmark, where flat lands and short distances make almost every destination reachable to the average cyclist) as well as in Asian, Latin American and African countries, mostly favored by economic conditions. In places where the bicycle has a strong presence, planners have to accommodate them through some interventions, such as special lanes on the streets, exclusive bike paths, racks for parking, etc, but these interventions are small compared to other means of urban transportation. The bicycle is indeed more than a respectable form of transportation, however, it is not capable of satisfying all the demands for mobility in a city. Since cycling depends on human power, it is subject to the physical limitations of the individual, and so it is not a feasible option for some people. Distances beyond 5 miles start becoming increasingly difficult for most cyclist and a daily trip of more than that can be challenging. The regular cycling speed is around 10 mph (16 km/h), considerably faster than walking but also problematic in large urban areas. Additionally, bicycles offer no protection to the rider and because of the difference in speed, weight, they can be hazardous when mixed with other forms of transportation in the city. Inclement weather, very high or low temperatures, snow, rain, high winds, etc. also affect bicycle travel significantly and limiting its efficiency. Thus, it is natural that bicycles are more popular among the young and in places where natural conditions are favorable (flat terrain, good weather).

Motorcycles, scooters, mopeds

Motorcycles, scooters, mopeds and other small motorized contraptions are also legitimate means of urban transportation. They provide some of the advantages of the bicycle without relying on human power. Sitting somewhere between the bicycle and the automobile, these forms of mobility are most popular in European and Asian cities with high density, mostly because they adapted to the urban configuration much better than the automobile: they move through the traffic much more easily and are more convenient to park. Although somewhat heavier, these vehicles are barely larger than a bicycle, taking about 1/6 of the space required to park a car. Equipped with a motor and a front wheel capable of tight maneuvering, motorcycles and scooters can move around in tight urban spaces almost without problems.

Safety, however, remains a major drawback. These machines can move at the same speeds as an automobile, while offering just as little protection to the rider as a bicycle. And while engines in motorcycles are small, most of them are not designed with pollution controls in mind.

Fig. 1.6
Scooters in Vietnam.

Cars

Cars are by far the most prominent form of transportation inside and outside cities. They are wheeled vehicles with its own engine for propulsion that run on the streets and can carry up to eight passengers. The popularity of the automobile responds to a basic human desire to move around freely without constraints, comfortably and with minimal effort. The most obvious advantage of cars is the expansion of the individual physical limitations of human-powered locomotion. In other words, it allows people to be relatively quickly at distant places that would otherwise be out of reach by walking. Additionally, because cars are privately owned, they are available on demand and not subject to schedules or fixed routes (at least in theory) and offer an exclusive non-shared space. Following an almost linear evolution, cars have been progressively adapted to meet almost any kind of travel need, provided there are sufficient refueling points between the origin and the destination. They can reach virtually any urban or rural location. Additionally, there is an expectation (sometimes grossly inaccurate) that car travel will be faster than other transportation options because there is no waiting time, no delays in transfers and no unnecessary stops.

Still, current automobiles do not solve all transportation needs. There is always a segment of the population that cannot drive or does not have the economic means to buy an automobile. However, the massive adoption of this form of transportation and a set of assumptions that have not changed over the years, have resulted in problems of global proportions. Most analysts agree that car travel is the main reason for urban sprawl, and a decisive factor in congestion and environmental concerns (pollution, energy waste, depletion of natural resources).

But the problem is not easy to solve. Cars have become so important to our daily life that they are, in fact, much more than just a means of transportation. Unlike bicycles and motorcycles, they offer a private enclosed space that can serve many other purposes beyond mobility. People in their cars not only drive, but also eat, sleep, shave, put make up on, get dressed (and undressed), listen to music, read the newspaper and practically everything in between. In many cases, cars represent a lifestyle and are a deliberate reflection of the economic and social standing of their owners.

The production of automobiles is the largest single manufacturing enterprise in the US, and General Motors is the largest corporation of any kind in the world.

The role and significance of the automobile as a means of transportation, and its relationship with the built environment are expanded on the following chapters.

Paratransit

Paratransit is a category of transportation that groups all those vehicles that provide a public service with rather small units. Technically, they constitute public transportation, but they have more flexibility than transit systems. The units (typically vans, shuttles or mini-buses) carry more passengers than automobiles and taxis, and the transportation service can be

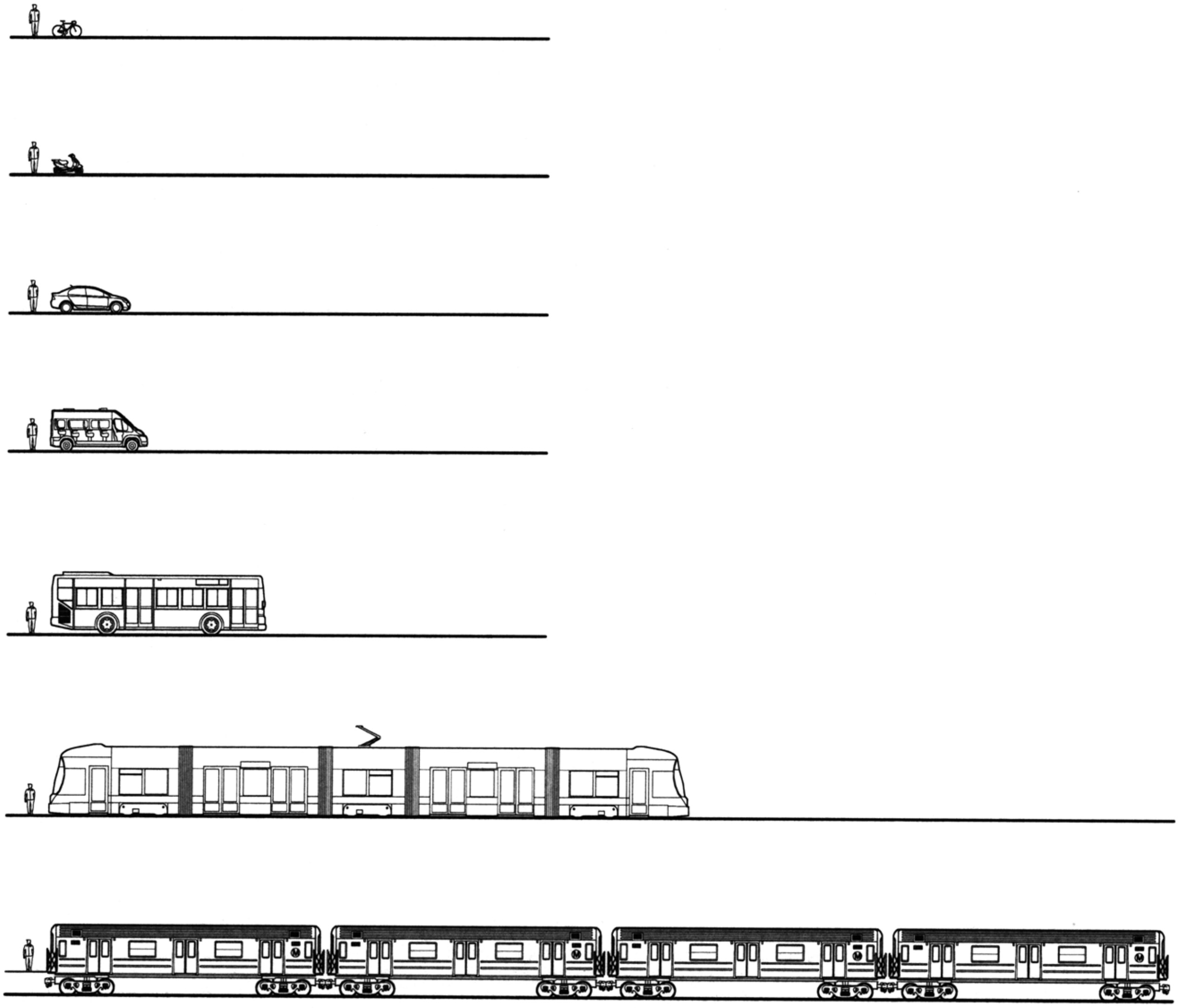


Fig. 1.7 (below)
Diagram of different urban mobility vehicles to scale. From the top: bicycle, scooter, car, paratransit, bus, light rail, subway.

customized to a particular group of people. Good examples are airport shuttles, university campus shuttles, commuter vans.

Buses

Buses are larger vehicles that are individually driven and operate over the streets accommodating many passengers. Modern buses are the children of street cars and gasoline engines, which liberated the units from the predetermined energy line. They run on public streets with mixed traffic along a predetermined route and schedule. Riders pay a fee, usually when entering the bus.

They offer a basic transportation service to the public, without requiring advanced engineering or special infrastructure since most cities are already adapted to vehicular traffic.

Despite many advantages, buses suffer of poor image and are seen as the mode of transportation for the less-wealthy segment of the society.

Similar to other means of transportation, buses have not changed significantly in their configuration since their inception. Buses are large prismatic volumes for the passenger compartment usually with seating, but with enough room for riders to stand up and walk inside. The engine is located at the rear, while the driver sits at the front of the vehicle and doors are aligned on one side. Naturally, there are still many variations in sizes (from minibuses to double-deckers and articulated buses, etc), but most of the research and development has focused on better engines, smoother and more comfortable performance and appearance.

Buses do not require advanced technology and since they run on the existing city streets, they constitute a low investment form of mass transit. Additionally, units are available from many manufacturers and can be acquired in low numbers, making this an attractive choice for smaller urban areas. One of the most interesting benefits of bus-based networks is the flexibility in operation, since they are not constrained to tracks or electric lines. Routes can be changed on-the-fly in case of unusual events (accidents, weather conditions) but they can also adapt to fluctuations in the demand in relation to land use.

As a means of transportation, energy consumption for buses (as well as other shared-based systems) can be vary from highly efficient to disastrous or unsustainable depending on the passenger load.

At the same time, exactly because bus networks are not heavily automated, they require more personnel per number of passengers than other transit systems. And most buses still present all the environmental problems generated by gasoline and diesel engines.

Running on city streets is both an advantage and a difficulty, because buses will get caught in traffic congestion, greatly reducing the quality of service. Ingress, egress and fare collection can also impact the ability to run the service under a reliable schedule, which is one of the main difficulties bus services have to face. Finally, the comfort level for passengers is still seen as a barely satisfactory.

Because buses can run on long routes and still have a relative high (and variable) density of stops, and several bus routes can overlap in areas of higher demand, they can be implemented both as the only (or main) transit mode in a city or as complement to a rail-based network.

Bus systems require stops where riders get in and out of the transit network. These stops must be distributed throughout the city, sometimes very frequently, but they can range considerably in their requirements. The most basic stops can be as simple as a sign on the sidewalk where people wait for the vehicle. More elaborate terminals offer shelter, information, and other services.

A variation of the bus network is the so-called Bus Rapid Transit. In reality, these services are the same as regular buses but they employ more advanced vehicles usually running on expanded physical facilities, such as preferential roads. The intention is to offer a faster, more reliable service. These systems are often aided by the use of computer-based control methods, and improved designs of stops for faster passenger ingress and egress. However, Bus Rapid Transit, often gets in conflict when it is implemented because these buses usually take lanes and roads that were already in use by other vehicular traffic. Still, they are still a valid option for mass transit and in some cases very successful.

Trolleybuses

Trolleybuses are considered a distinct mode of transit, but they are essentially identical to buses, except they are propelled by an electric motor that draws power from a network of suspended cables. It can also be said that they are similar to streetcars, but instead of running on ground tracks units are tied to the overhead line of electric wires, which gives the vehicle more flexibility in moving across several lanes on the city streets. Trolleybuses are also a legitimate form of public transport, but they have never reached great popularity. The advantages of trolleybuses are principally derived from the use of electric power, which translates in no emissions by the vehicle itself. At the same time, they require a network of wires running over the streets, which is not a welcome sight, creates conflicts with other activities and, fundamentally, greatly limits the flexibility in service routes. Compared to standard bus systems, the required infrastructure is larger and more complex, and so is the cost of implementation.

Streetcars, light rail

Trams or streetcars are vehicles that run on a network of rails on the streets of a city. They are lighter in use, weight and construction than trains, and in many cases they are mixed with other forms of traffic. Units are electrically powered and carry many passengers in a single vehicle or in short trains. First streetcars appeared in the early 1800s pulled by horses, a hundred years later there were about 60,000 electric streetcars in operation in the U.S. alone. (Grava 2003)

They take a spot in urban transportation between buses and the metro system (heavy rail), and the difference with trolley buses is that they run on rails, and sometimes with larger cars. Quality of travel is regarded as somewhat better than in buses. Movement is smooth because travel is on a straight line and on uniform rails. Because tracks ease the task of moving, light rail transit can move a considerable number of people with little energy consumption. Additionally, the tracks give stability and control of movement, and the chances of collisions with other vehicles are reduced. Because they are electrically powered, cars themselves do not produce air pollution and are practically noiseless.

There are some drawbacks, of course. First, all rail systems are fixed in place, so they offer no flexibility in

Fig. 1.8
Light rail car in Portland, OR

the route of operation. Although not all light rail is mixed with city traffic, when it is, it offers advantages and disadvantages at the same time. An exclusive right-of-way always represents a higher cost in infrastructure (segregated or elevated rails, platforms, etc) whereas tracks simply placed on the streets can lead to better integration with the city life as well as interference with cars, buses, bicycles and pedestrians.
The most important aspect for the implementation of a light rail system is its cost. Unlike buses that can be acquired in small numbers and start operating almost immediately, any rail system requires the investment and planning of not only the cars (many times more expensive than buses), but also of its infrastructure.

Heavy rail (metro)

Heavy rail transit, also known as metro, subway, underground, etc. is a passenger transportation mode for urban areas that runs on exclusive rights-of-way, almost always on rails. They consist of short trains with cars that are electric and self propelled. Their main advantage is their ability to move large masses of passengers, which no other transit system can match. Thanks

Fig. 1.9
Tokyo subway.

to its exclusive tracks, they typically offer a high frequency and a fast service.
First heavy rail systems were placed on elevated tracks since there was no room to accommodate a locomotive running on the street level. The first metro system to run underground was implemented in London in 1863. Now, most cities that operate a metro service do so in tunnels below street level, especially in dense downtown areas, although it is common to run portions of the system on the surface as well. This offers a major advantage because it occupies minimal valuable surface at the ground level, does not contribute to street congestion (in fact, it alleviates it) and eliminates any conflicts with other city traffic. The use of tracks is also somewhat efficient, because friction is reduced thus requiring less energy to move the train. The combination of exclusive rights-of-way and tracks allows for higher speeds than other transit systems (60mph is not uncommon) and the travel is smooth and relatively comfortable. All metro systems are electric, so they do not contribute to air pollution, and electric lines are also placed underground so they do not affect the visuals as streetcars do. The use of exclusive paths also minimizes the chances for accidents, and

many aspects of its operation can be easily automated.

At the same time, construction below grade in already densely urbanized areas is extremely expensive and many times, prohibitive. The main disadvantage of any metro system is the capital investment required to create a new line, as well as the long and difficult process of implementation, which takes years of planning. This makes heavy rail transit an option for only a few large urban areas in the world that have a population large enough to justify its major cost. This problem is further exaggerated due to high costs of maintenance, because the system only runs at full capacity during a short window of time every day. As a consequence, almost all metros in the world operate at deficit. Additionally, as any other rail-based transportation method, metros are among the most inflexible of all transit systems and practically incapable of adapting to changes in the land use. Only very few cities in the world can support a metro network that is comprehensive enough to cover most of the needs for urban travel. In most other cases, it is common for heavy rail transit to serve only specific corridors of the city and be complemented with other services, such as light rail, buses or taxis.

Commuter rail

In large metropolitan areas, rail-based systems can expand considerably and provide very efficient transportation for even larger amounts of people. Unlike metro service, commuter rail almost always operates on the surface, although it still uses exclusive rights-of-way, segregated from vehicular and pedestrian traffic. It covers longer distances, but at lower frequencies, with increased services when demand is high (rush hour), and almost all regional rail systems are designed in a radial pattern to connect suburban areas with downtown.

Other modes of urban transportation

Many cities enjoy several other alternatives to move people around. Some of these options are influenced by natural constraints. For example, in urban settlements next to a shore, it is not uncommon to find waterborne modes with public services, but they usually have a small impact in the overall scheme of urban transportation. Still, ferries operate short trips for passengers regularly and frequently between two points along waterways, and remain effective as a means to overcome water obstacles.

In other places, where terrain plays a major obstacle, cable cars and aerial tramways may act as a reasonable mode of transportation, although there are not many cases that justify them as an efficient alternative.

Lastly, it is necessary to mention the role of airborne means of transportation. Most air travel is best suited for long distances, but helicopters can be effectively used for urban mobility purposes. This is mostly restricted to emergency response, police operations and in very few cases as personal mobility for VIP service.

Mixing public transportation with personal mobility

The concepts of private mobility and public transportation, however, are not necessarily antonyms. In fact, because of their differences, one method is usually better suited for certain situations than the other. For example, mass transit is a great choice for commuters in cities with a number of dense nodes, since there is a more or less steady flow of people in every direction. On the other hand, if there is only one concentrated urban core surrounded by low density housing, it becomes increasingly difficult to run a profitable mass transit system without enough passengers on each line. Certain geographic conditions can favor the implementation of mass transit along a naturally defined line (rivers, coastlines, etc), while other natural obstacles can make mass transit systems impossible or extremely costly. Personal mobility devices always have an advantage when there is not enough people to move around at the same time or in the same direction, and cities usually have a combination of different situations, so in many cases, mass transit and private transportation can complement each other. For example, mass transit works better during rush hours because they can move large amounts of people very efficiently, but personal mobility might be a better choice at other times of the day. Flexibility of service in individual mobility versus high speeds of transit is also a common reason to couple these services. The transit system may run faster on congested areas of the city but the passengers complete their trip through some other means that takes them precisely to the desired location.

Intermodal points of transportation

Intermodal transportation involves transfer to and from one mode of transportation into another. Intermodal facilities come in many different scales and offering many combinations. City airports are an example of an intermodal point, where passengers swith between some kind of ground transportation to air travel and viceversa.

Park and ride facilities are public intermodals points that allow commuters traveling into the city center to leave their vehicle parked in the outskirts and continue their travel by some kind of mass transit such as bus, train, etc. The vehicle is parked during the day and retrieved when the commuter returns. These programs are usually sponsored by the city authorities with the goal of alleviating congestion in dense areas, so it is common that one or both services (park or mass transit from that point) be offered free of charge. Park and ride and other intermodal points can be highly effective because they generate enough demand to extend a transit line to the outskirts of a city, where the density of population would otherwise make this an unsustainable option from the economic perspective; and commuters only need to drive their private automobiles to the nearest stop rather than all the way into the downtown area.

Taxis

For-hire assisted mobility is as old as the wheel itself. Before the automobile-based taxi appeared, similar services were offered with human-powered engines (hackneys) or with horse-drawn carriages (or equivalent). Modern taxi cabs are available to anyone on the street and offer almost the same advantages as a privately-owned automobile for a short period of time. While they are not always available on demand, they can still provide point-to-point mobility, with the benefit of having a chauffeur who drives the vehicle. Because of this, fees are high and it is usually considered a premium service, but it can also act as an emergency service or a backup option when driving your own vehicle is not a possibility.

Fig. 1.10
Taxis in New York City.

Therefore, taxi cabs sit in between public and private transportation. Taxis (and other comparable services such as rickshaws) are still very efficient, because, just like public transportation, they offer a shared service. The vehicle can immediately pick up a new passenger after dropping off one that has reached his/her destination. The main problem with taxis seems to be a lack of information. Taxi drivers spend too much time and gasoline looking for passengers while passengers wander the streets unable to find a free cab. To overcome this problem, the service has been efficiently coupled with the use of the telephone and radio. Users who need personal transportation can call a dispatcher who then alerts to all units nearby of the exact location of a passenger.

Car pools

Car pooling also has a spot somewhere between public and private mobility. It consists of an agreement among a group of people that have more or less the same travel patterns (in terms of location and schedule). This is a fairly common practice for commuters. They all ride in a single (standard) automobile and share the cost of transportation. While the service is not freely available to the public, it's a major step up in terms of efficiency, with excellent savings for the users. This also represents a major advantage for the city, since fewer cars in transit translate into less congestion, less pollution, etc. Therefore, cities with traffic problems usually give incentives to this practice by reducing or eliminating fees, giving special lanes for circulation, etc.

Fig. 1.11
Car pool lane.

Bus-bike

In recent years, newer combinations of public and private transportation have appeared. In Los Angeles, for example, the city has implemented a program called Bikes on Buses. It is now common to see buses equipped with special racks on the front. These racks accommodate up to two bicycles, allowing passengers to ride the bus for long distances and complete their trip (to and from the bus stop) on their personal bicycle.

Fig. 1.12
Bus equipped with bike rack

Ferries

In cities next to large bodies of water, it is common for water-based transportation systems to offer their services not only to passengers by foot but also to cyclist and drivers. As mentioned before, ferries are part of the transit network of a city. Their service is available to the public in general, and they run on a regular schedule across a water route. Since these ships can be considerably large, they may include a space dedicated to transport other forms of personal mobility inside the vessel as well. Just like the bus-bike, passengers arrive to the terminal point (stop) of the transit system by some method of personal mobility, continue traveling in a shared vehicle until another stop of the route, and finish their trip to their destination by personal mobility again. The capital cost of a ferry is much lower than building a bridge or a tunnel, but the service can be considerably slower as well, so it remains a valid option where this kind of infrastructure cannot be built for economic or geographic reasons. But the predominance of the automobile has justified the construction of massive works of enginnering across great distances, reducing the popularity of ferries that carry vehicles.

Bike sharing

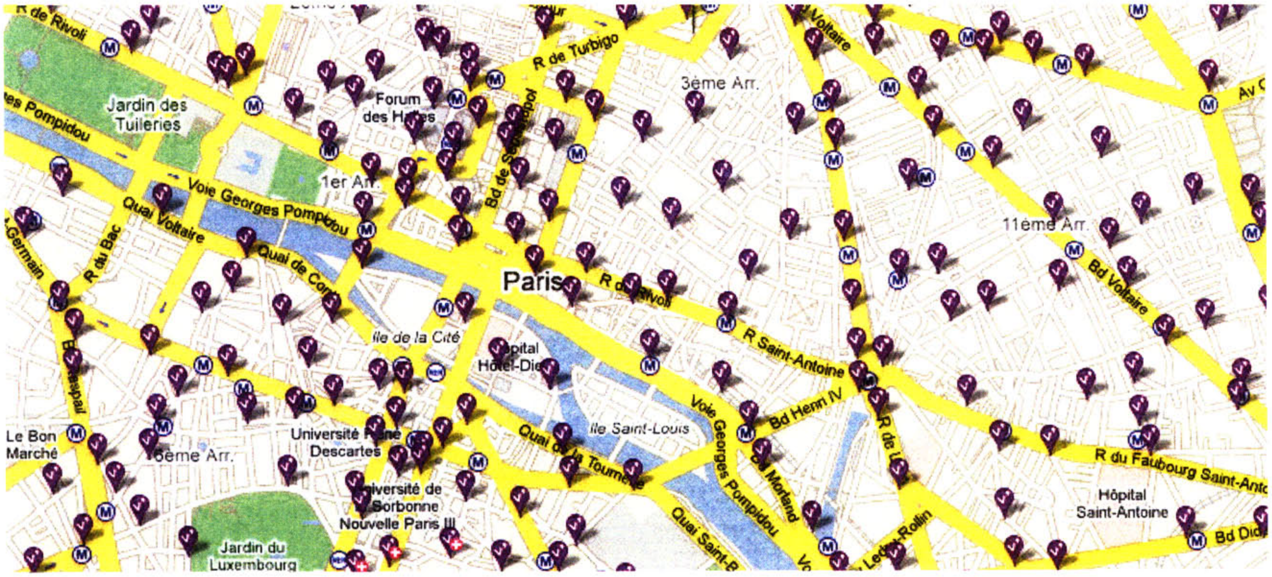
In recent years, however, the need of increasing the efficiency of transportation systems has been gaining popularity and has driven creative minds to find more viable solutions. The case of bike-sharing is one example of this kind. In recent years, cities across Europe have seen an explosion of programs that encourage people to move around the city in bicycles.
Vélib', in Paris, France, is one of the largest bike-sharing programs. It was launched in 2007 with an initial number of 10,600 bicycles distributed over 750 locations. It is said that these numbers have duplicated in one year. [2]
A similar program called "Bicing" offers the service in Barcelona, Spain, at a smaller scale, but also growing rapidly. Bikes are parked and locked next to a station that releases the bicycle from the support frame when the card is recognized by the reader. The system is based on a membership program, and targeted to commuters, workers and residents of these cities rather than tourists.
These programs use a number of measures to prevent people from keeping the bicycles for extended periods of times -which attacks the very essence of the

Fig. 1.13
Vélib' bike sharing in Paris

program by decreasing the shared usage. First of all, they use a membership model, and members are uniquely identified by means of an RFID card, or by entering a PIN into a terminal keyboard. At the same time, they have financial incentives in place. For example, the use of a bike is free for the first two hours but there is a cost for additional use and heavy fines for long periods of time.

These programs offer a very interesting model, because they are based on one-way trips. This means, the rider can drop off and lock the bicycle at any other location in the city. Car sharing programs, on the other hand, require users to return to their original location. This is a major difference, because the system needs to be able to keep the distribution of resources in such a way that ensures availability at all times. Bike sharing programs usually have vans or trucks to redistribute units when the balance is altered. If this is not handled properly, users will complain of difficulties in finding a rack with available bicycles or a location with empty slots to return one.

Fig. 1.14
Vélib' bike rack locations in Paris



Car sharing

The same idea of bike-sharing can be implemented with automobiles: some private or public organization makes a fleet of cars available to a large pool of people who then get access to personal mobility on an as-needed basis. Generally, people have access to this fleet of cars by joining this organization and paying a fee each time they use a vehicle. The main difference with traditional car rental companies is the ability to use a car for a short period of time, usually into one-hour or thirty-minutes segments, and that the units are distributed in regular parking spaces throughout the city.

Most studies recognize three basic shared-use vehicle system models: (1) neighborhood model, (2) station cars and (3) multi-nodal; although there are many hybrid modes (Bart, Shaheen 2002). The two largest car sharing companies in the U.S. (Flexcar and Zipcar) are both examples of neighborhood models that require two-way trips (i.e. the driver must return the car to the original location). In general terms, car sharing is typically located in dense urban areas with good mass transit systems. The assumption is that people use public transit systems for most of their trips but, additionally, they have access to individual mobility when traveling outside the transit network area, at different schedules, or when carrying large items. In fact, recent data from research in car sharing programs have demonstrated that members tend to use more public transportation after joining a car sharing organization (Millard-Ball 2005).

Car sharing is particularly interesting because of the elevated costs associated with car ownership, which are much higher than that of a bicycle. Despite their widespread adoption, in most cases, cars still represent the second most significant purchase for individuals and families, after a home. Additionally, there are other unavoidable costs associated with car ownership, such as fuel, insurance (which is compulsory in most cases), other consumables (oil, tires, etc.) as well as any repairs needed. In car-sharing systems, instead of being absorbed by one individual, all these costs are divided among a larger group of people, and paid for on a per-use basis. That is, those who drive more pay more for having access to a vehicle, and those who use the system less, do not pay as much.

As a consequence, these organizations also increase mobility options to lower income market segments, since users do not need to meet large upfront costs to use a car. Furthermore, surveys suggest that because they have to pay a fee to use a car, carsharing users are more conscious of the costs associated with driving and more likely to weigh alternative travel modes, which is then likely to result in less miles traveled per individual.

Car sharing in its current form was first implemented in Switzerland and Germany in the late 1980s. Other European countries soon followed. By 2004, there were 70,000 car-sharing members in Germany and 60,000 in Switzerland. In the U.S. the concept came a few years later, but it has notably expanded in recent years, reaching 61,652 members in December 2004, sharing 939 vehicles. (Millard-Ball 2005)

Besides the economic factors, car sharing can also present a number of advantages associated with the increased efficiency of sharing a resource, such

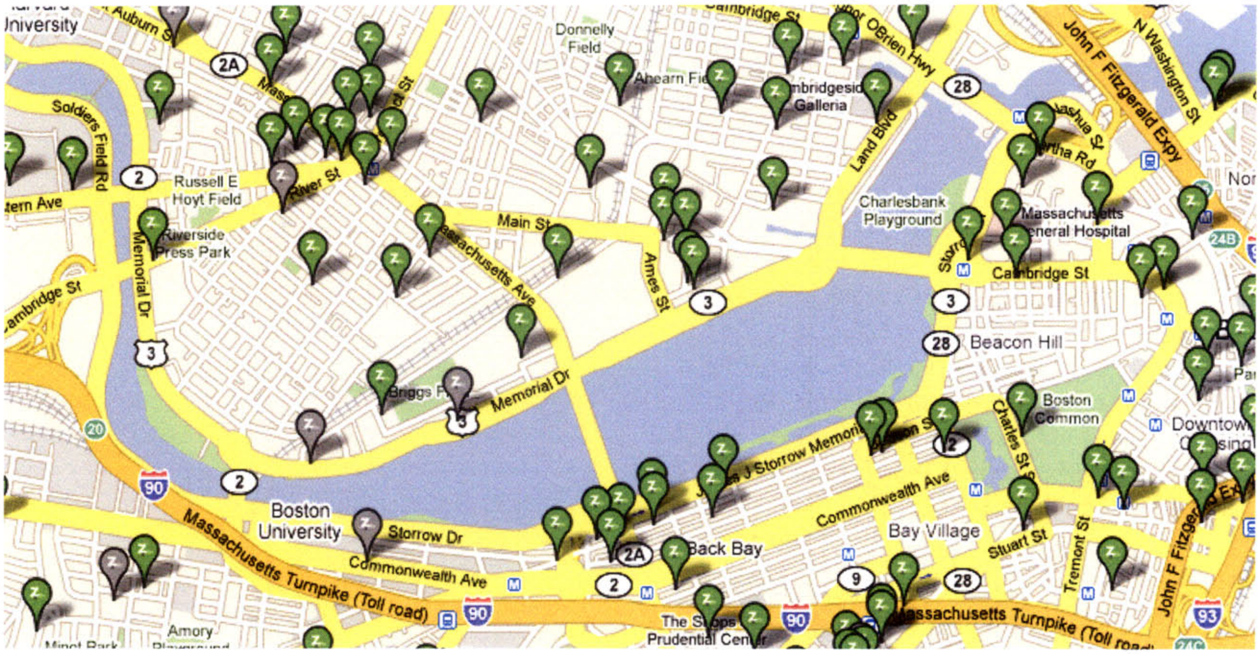


Fig. 1.15
Distribution of ZipCar car-sharing vehicles in Boston, MA

as reducing the number of parking spaces needed, which in turn, translates into a more efficient land use. In other words, because usage is distributed over time, one automobile is enough to satisfy the mobility needs of -for example- four people, rather than one. So, instead of four people having four cars, which require four parking spaces, only one parking space is needed.

By having access to comparable personal mobility on demand for ocassional trips, an individual or family may be able to abandon the purchase of a car (or a second, third), thus reducing the need for privately-owned vehicles and their associated parking requirements. A study in the US and Canada shows that each car-sharing vehicle removes between 6 and 23 cars from the roads and European studies suggest that each car in a shared organization eliminates between 4 and 10 privately owned cars (Shaheen, Cohen 2006) These numbers vary greatly depending on the ration of members over units available, location,

density of population, demographics and other factors. In 2005, the Transportation Research Board published a report specifically about car sharing, and collected data from North American and European organizations and found that the ratio of 1:27 of cars to members is a consistent estimate across several studies. This ratio would mean that each car-sharing vehicle is estimated to replace 14.9 cars from the streets, which is a net reduction of 13.9 vehicles. This estimate, however, did not include data from members who reported delaying the purchase of a vehicle, so the reduction could be in fact greater. For the 939 car-sharing vehicles in the US in 2004, this estimate yields a reduction of more than 13,000 cars. (Millard-Ball 2005)
Such an impact should also have effects on the amount of traffic and congestion, air pollution and parking requirements in cities.

Notes

[1] U.S. Census Bureau. http://www.census.gov/population/socdemo/journey/mode6790.txt

[2] http://www.parisinfo.com/professionnels/100313/velib-

driving demand

cars and the city

The relationship between cities, its people and their cars has been a dramatic one, since the motor car appeared in the late 19th century. All means of transportation in the past have had an impact in the way we live and in how we arrange our cities, but the automobile has profoundly reshaped the human landscape, probably more than any other form of transportation, if only because of its ubiquity. Their predecessor, the horse and cart, had already created demands for roads for moving, stables for sheltering of the animals, and filled the city streets with waste matter. Transit systems also affected land use by favoring accessibility in points of the urban fabric, but their implementation was costly and slow. However, when the motor car appeared on the scene with the promise of unrestricted mobility without effort, it quickly captured the popular imagination, and its widespread adoption meant deeper changes in the life of the city.

Fig. 2.1
Fifth Avenue, New York City, 1900

Without trying to take into consideration all the psychological implications that the automobile has created in modern global culture, it is safe to argue that it offers an extension of the human physical capabilites unlike any other artificial device. They allow people to be physically present at long distances in such short periods of times that would be impossible by natural means. This purely utilitarian argument should be strong enough to attract large numbers of people, but there were many other factors that conspired in the adoption of the automobile as the most prominent form of transportation.

Infrastructure

First, it is necessary to review the most basic demands imposed by cars. Like any other system of transportation, cars require at least three components to operate: the vehicle, the right of way and the terminal. For a example, for a rail system, these components would be the train, the railroad tracks, and the terminal. In the case of automobile, they are: the car itself, the roads and the parking space.

The most obvious adaptation to the presence of the car is the redefinition of the city streets, and the expansion of roads and highways as a primary communication artery between two points. Currently, we take for granted that the function of streets is to permit vehicular circulation, but city streets existed before the advent of the automobile to serve many purposes, including transportation. City streets are the primary support for any kind of traffic and they provide direct access to the houses, businesses, parks, etc.. Stone paved roads can be traced to 4000 BC (Lay 1992), but in the last one hundred years with the proliferation of cars, their use increased exponentially. This created an unprecedented demand for linear durable surfaces with enough room to accommodate vehicular traffic; a task that was undertaken almost exclusively from an engineering standpoint.

Generally speaking, modern city streets can be classified into three categories: streets, arteries and expressways. Streets carry low traffic loads but provide direct access to destination points for people. Local streets are shared by different means of transportation often including the presence of pedestrians. They can also act as meeting points for people, playgrounds for children, etc. so traffic moves at low speeds to minimize conflicts. Arteries are larger roads carrying heavier loads of traffic. They can also provide direct access mostly to businesses, high density housing and important civic places. Expressways, in turn, do not offer access to destination points and are only used to carry high loads of traffic at higher speeds. Pedestrians are excluded from using expressways, and only certain kind of traffic is allowed because speed, safety and other characteristics make them incompatible with each other. Nowadays, due to the ubiquity of the automobile and its prominence as a means of transportation, city streets are designed to meet the requirements of vehicular traffic. Kunstler states that suburban streets of almost all post-war housing developments were designed so that a car could comfortably maneuver at fifty miles per hour -no matter what the legal speed limit is. "The width and curb ratios were set by traffic engineers who wanted to create streets so ultrasafe for motorists that any moron could drive them without wrecking his car." (Kunstler 1994)

Similar solutions were required for those times when the car is not moving. When idle, these large and expensive machines need to be safely put out of the way, which also involve some notable spatial considerations in the design of the city. In order to accommodate all these cars, urban areas dedicated special zones and regulations to control parking. Parking can be classified into three basic types: on the side of the street (on-street), in open parking lots (off-street), or in buildings above and below ground (garages, also considered off-street).

In addition, it was also necessary to create a distributed network of stations that can provide cars with the necessary supply of fuel to keep these vehicles running; as well as structures destined to the production, retail sales, repair and maintenance of cars.
Even at the small scale, these requirements meant some kind of intervention in the landscape. But the massive adoption of the motor car all over the world, which still has no signs of decline, continues to pose a major challenge for urbanists and government officials.

Adoption of the car

Although it can be easily argued that cars somewhat changed the dynamics of the modern city everywhere, in older towns with strong heritage -such as in Europe and Asia- the car had a weaker impact than in younger cities. The case of the U.S. is somewhat unique, though. When the car arrived to the scene at the end of the 19th century, American cities were young and rapidly growing. A fundamental factor for the mass motorization in the U.S. was the industrialized techniques applied to car manufacturing by Henry Ford. For a few decades, cars had been essentially hand-made by skilled craftsmen, and thus expensive and only accessible to the wealthy minority. Ford designed the car around its manufacturing process, with standardized and interchangeable components that made the line production itself possible. By 1920, almost half of the vehicles in circulation were made by Ford. In 1927, the U.S. was building 85%

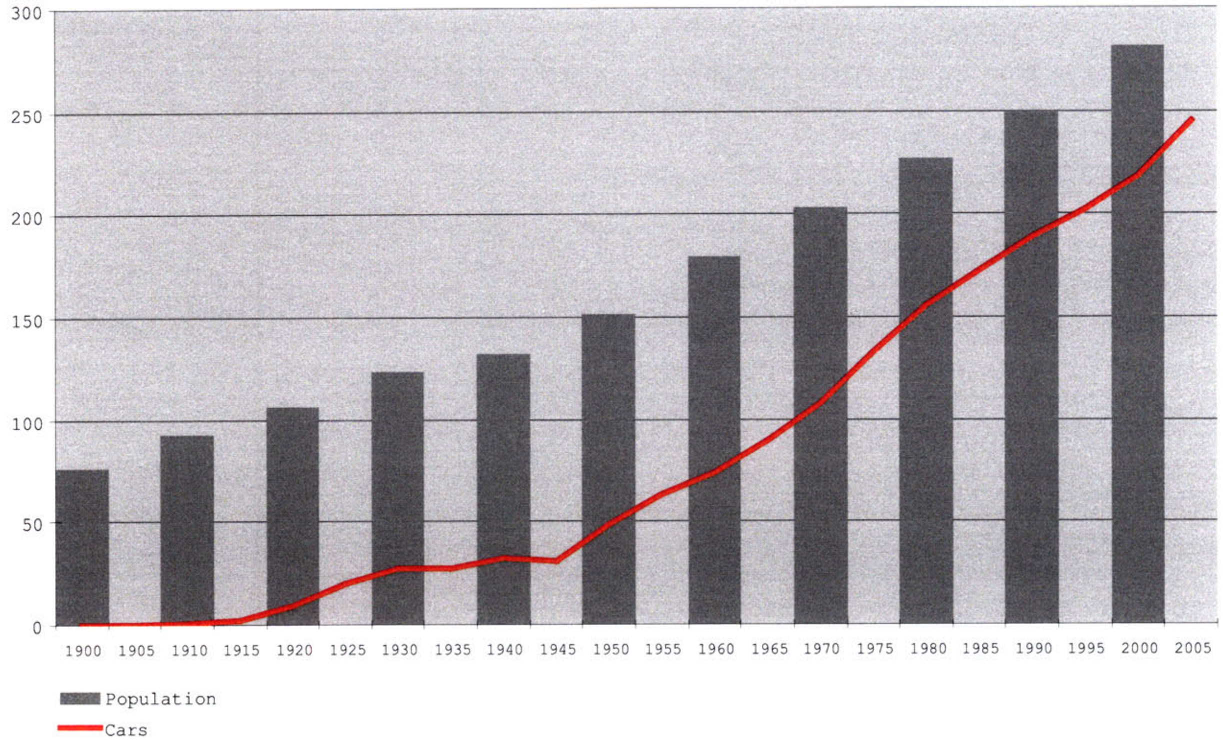


Fig. 2.2
Population and car growth in the U.S. [1]

of the cars in the world (Hall 1988) and in 1930 there were already approximately one car for every five americans. Since then, no other country has enjoyed the economic and geographic conditions necessary for the development of the automobile in a similar scale. In Europe, it was difficult to find enough land, whereas in places such as Latin America, India or China, economic conditions restricted the adoption of the automobile to a smaller percentage of the population.

The statistics are remarkable: in 2001, 92.1% of the U.S. households owned at least one vehicle, and over 60% owned two or more vehicles. [2].
In 2006, 87 percent of the driving-age population was licensed to drive a motor vehicle as compared to 57 percent in 1950. Before 1975, the country had roughly 1.0 vehicle per licensed driver. Since then, the ownership of vehicles on a licensed driver basis has been

increasing at an accelerating rate, reaching 1.2 at the end of 2006 [3]. According to a study, car ownership in US cities in 1990 was 50% higher than in European cities and six times the rate of Asian cities, while the usage of cars (as measured in km per person on a vehicle) almost three and eight times higher respectively. (Newman, Kenworthy 1999)

Urban Landscape

Although every developed country has built important infrastructure in the form of roads, highways, parking lots and garages, the massive vehicular infrastructure developed in the U.S. to support this new lifestyle created distinct urban patterns.

The automobile has developed communities with easily identifiable characteristics. With the right kind of incentives (such as adequate road constructions and segregated zoning, for example), the liberty of personal transportation spread homes into very low-density settlements of single-family detached houses. Living near the city center was no longer a necessity because it was assumed that the car would

Fig. 2.3
Suburban landscape outside Atlanta, GA

provide with immediate transportation to any destination whenever required. The process makes residential zones shift to the outskirts, creating sub-urban areas.

Most activities, such as shopping, recreation or commuting to work, require the use of a car as a result of the neighborhood's isolation from the commercial and industrial zones. In most of these cases, the car is the driving force and the only option. Homes are separated so far apart that common services, shopping, cultural and educational facilities and even mass transit systems would only provide service to very few people within walking distance, making them economically unsustainable. In contrast, higher densities reduce automobile ownership in part because more places can be reached by foot, by bicycle or public transport. High rates of automobile ownership are both a cause and a consequence of this pattern and this spiraling effect has been labeled the automobile dependency.

In these cities, collector roads and highways connect suburban communities with the city center and with one another through the use of cars, but at the same time, they isolate them in practically every other way. A walk or bicycle ride between two adjacent suburban neighborhoods might be impossible or too dangerous to attempt. The impossibility of accessing the city resources by any other means also implies that those resources are not available to younger people under the legal driving age as well as to some elderly people, disabled or those who cannot afford the cost of owning and maintaining a car. (Kunstler 1994)
In turn, as urban sprawl moves residential areas to distant locations, there is a deterioration of the city centers. Wider streets and parking lots start replacing valuable land, and the

migration of shopping and recreational activities to the suburbs make walking around downtown areas less attractive. (Kushner 2004)

In 1990, Newman and Kenworthy published an extensive report on automobile dependency with data from major urban areas in the US, Australia, Canada, Europe and Asia. One of the main indicators of the relationship between cars and cities is the energy consumption for travel purposes. US cities use more than 5 times more per capita of transportation energy than Asian cities twice as much as European cities.

The cycle of dependency has effects on the use of any other means of transportation. The use of transit systems rapidly declines and becomes unsustainable in cities with high automobile dependency. In many cities in the U. S., transit barely covers 1% of all the travel needs, and even New York, with the most comprehensive public system of all US cities, it only reaches to 11%. In contrast, European cities, on average, satisfy 23% of all passenger transportation needs by transit. Wealthy

Fig. 2.4
Intersection of I-10 and I-405 between Santa Monica and Los Angeles, CA

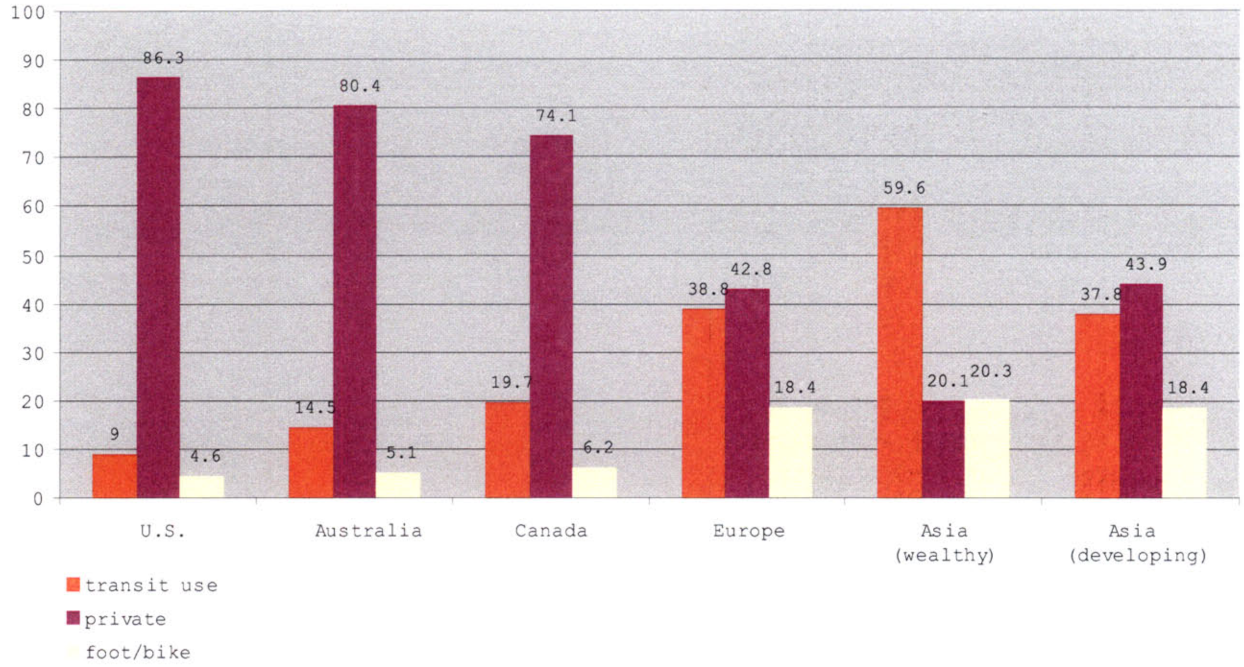


Fig. 2.5
Transit, automobile and foot/bike use in the U.S., Australia, Canada, Europe, and Asian Cities. Source: Kenworthy, Newman 1999.

Asian cities (Tokyo, Hong Kong, Singapore) had 496 trips per person in one year on transit system. European cities averaged 318 trips while US cities reached only 92 trips.

A major factor in the adoption of cars as a means of transportation is dictated by the economic conditions of a particular city or region. Automobile dependency is more evident in wealthy societies. However, economic conditions are not the only aspect of the proliferation of cars. European cities have enjoyed a higher per capita city wealth (called gross regional product in their study) than U.S. cities for the year studied ($32,000 versus $26,000 respectively) and still, the car use per capita (VKT) in Europe was less than half the average of the US cities studies (10,870km against 4,519). Geographic and socio-cultural conditions can also be limiting factors for the development of mass transit systems.

The problem, of course, is easy to

understand. Given the right conditions (highly efficient manufacturing techniques, economic development, supporting policies) -as illustrated in the case of the U.S.- the number of vehicles can increase very rapidly, while the physical network necessary to support them is hardly able to grow at the same rate. The demand (number of cars in circulation) quickly outpaces the supply (roads, parking spaces, etc). But there is another dimension: even in prosperous societies that may be able to afford the massive expense associated with expanding the required infrastructure, supply is always conditioned by one crucial factor: space, which in the end, is not limitless.

Congestion

Cities are characterized by a concentration of resources and activities in defined locations. This means that a convergence of people and thus traffic is inevitable. In other words, when the number of people (and cars) in circulation exceeds the capacity of the city streets, congestion occurs. Congestion is a phenomenon that is not exclusive to vehicular circulation, and is characteristic of very successful endeavors.
Street congestion can be caused or aggravated by many factors, such as an unusual incident (an accident, weather conditions, etc) that obstructs the network and prevents cars from flowing at the usual rate, but it can also be recurring, simply because there are more vehicles trying to access the roads than what the network can actually support. The end result in both cases is a delay for all the units moving through the network.
In the U.S. this disparity between vehicle demand and road supply is easy to illustrate. Between 1985 and 2006,

Fig. 2.6
Congestion in China

vehicle miles traveled increased by nearly 100 percent, while highway lane miles only increased 5 percent during the same period. [4]. The average annual delay for every person using motorized travel in the peak periods in the 85 urban areas studied climbed from 16 hours in 1982 to 47 hours in 2003 [5]. Congestion is expensive, because people waste more time and fuel than in the equivalent situation when flow is uninterrupted and the network is below its maximum capacity. Furthermore, the additional time that cars are running at a slower pace on the network means generation of extra pollution. But completely eliminating the congestion dilemma might be an idealistic scenario. Ultimately, our society works in such a way that we all want to work, eat, sleep, entertain at similar times of the day partly for biological reasons but also to ensure that there are enough chances of social interaction. All these factors cause a large number of people to want to travel during the same few hours each day, particularly in the morning and evening (rush hour). Thus, unless our society changes radically the way we interact (which seems extremely unlikely to happen) or the network is designed to absorb the maximum flow during those peak hours and remain under-used for the rest of the time (which seems extremely expensive and ultimately unsustainable), some level of congestion should always be expected in prosperous conditions.

It has been argued that congestion may be the most effective solution of dealing with allocation of road resources (Downs 1992).

Parking

While congestion affects almost every kind of transportation method that runs on city streets to a certain degree, parking is an inherent condition of personal mobility systems. Unlike transit, which is always on the move and only stops for very short periods of time to pick up and drop off people, personal mobility systems operate on demand. That means that they have to be available to the user when he or she needs it. Therefore, almost all options for personal mobility are privately owned by the individual and need a place to be stored while not in use. Parking (or storage) of personal mobility systems become problematic when the scale of these requirements is significant. This is rarely an inconvenience for bicycles, mopeds, scooters and motorcycles because the dimensions of these devices are usually closely related to the dimensions of the person. Still, in countries like Holland where the bicycle is a massively popular means of transportation, certain parking structures can be challenging as well. Naturally, in the case of the automobile which usually has enough room to accommodate at least four individuals, the requirements (and the problems associated with them) are substantially higher.

Fig. 2.7
Bicycle parking in Sweden

The first parking structures gained popularity in the 1920s for the main purpose of protecting the vehicle's oil-paint finish from the elements. With the explosion of automobile ownership, the need for parking downtown became a preeminent development issue. Increased automobile ownership created pressure to reduce or eliminate on-street parking in favor of additional traffic lanes; it then caused a major expansion of off-street parking, resulting in the creation of both parking lots and garages. Today, 60 to 75 percent of all downtown parking spaces are located in off-street lots and garages, even in small towns with fewer than 5,000 people (Edwards 1994).
Off-street parking is particularly problematic because they directly

substitute land that would be usable for other purposes (to create more jobs, green spaces, etc). They break up the urban fabric with asphalt holes, creating greater distances between destinations, and making walking more difficult and less enjoyable.

In the U.S. alone, there were 250,851,833 vehicles registered in 2006 [6]. If we consider three parking spaces per vehicles at 200 square ft per parking stall, the total area would be 5280 square miles, equivalent to the size of Connecticut.

The impact of parking, however, is not only measurable in physical dimensions, but also in economic terms. Today, automobile parking is essential to most land uses and because car travel is so important, there are strict parking guidelines in regulations for almost any city. The adequacy of parking influences economic return on public and private sector investments and affects property values. There are real costs associated with providing parking, and they significantly affect real estate projects.

Already in 1965, Meyer, Kain and Wohl pointed out the significance of parking in relation to operating costs for the automobile, in their work "The urban transportation problem". Parking costs surpassed figures for maintenance and operation (including highways) and even car ownership and accidents. They also concluded that by far, the most important and easiest cost reduction in automobile-based transportation would stem mainly from reduced parking space requirements, but also from a widespread adoption of leasing or rental arrangements.

However, 97% of parking is presented as free in the US and most drivers assume that free parking is indeed free (Shoup 2005). UCLA Urban Planning professor Donald Shoup reveals the fallacy of the car parking status quo in his book The High Cost of Free Parking. Someone must always pay for the use of the land, the cost to build the facility, the lighting and so on. Additionally, there are design, construction fees, and taxes that must be accounted for. Initially, the developer pays for the required land, construction, and so on, but soon the cost is passed on to the tennant. Hotels, shopping malls, office buildings, etc. ultimately transfer these costs to their customers, visitors, users and employees indirectly as part of overhead. When cities make parking requirements for any kind of development, they effectively bundle the cost of parking spaces into the cost of the new construction. This makes driving more affordable but everything else, such as housing, more expensive, not only by adding one cost to another but also by restricting the available space for housing, commercial and other activities.

The problem of free parking is especially detrimental to the less wealthy segment of the society, because they typically own fewer cars, but they still have to indirectly subsidize all those parking spaces through hidden costs equally as the rest of the population. This also applies to different ethnic groups since they have different car ownership rates. At the same time, when one evaluates the cost of personal mobility per mile, hidden parking subsidies give the largest economic reward to the shortest trips, which in turn, encourage driving everywhere, even for those trips that would most likely be made by walking, biking or transit.

Parking presents an interesting paradox: It is estimated that there are four parking spaces for each automobile in circulation in the US. Yet, finding an available space to park in certain urban areas can be a major challenge. When they reach their destination, drivers waste valuable time and additional fuel looking for a space to leave the car which, in turn, makes the trip more time consuming, more expensive and more contaminating than strictly necessary. Problems of parking and congestion are also connected. In these areas where parking spaces are scarce, drivers need to spend additional time on the streets driving around in search of an available space. This means that in areas of high demand, there are also more cars on the street that have arrived to their destination but are still in circulation taking up road space.

The reason for this discrepancy lies in the intrinsic inefficiencies by the use of the private automobile. Transit systems do not need to park in areas of high demand. The vehicles used for transit are shared both in space and time. So they simply stop at a certain location where passengers get out and new ones get in, and continue their journey to the next stop. In contrast, because cars are usually owned by a single person, they remain unused for most of the time. According to the NTHS, the average trip duration by car is 73 minutes, which means that for the rest of day, the car is parked. That is, for 95% of the time, cars do nothing but take up space somewhere in the city. [7]

It is almost impossible to calculate the real cost of parking, simply because it is tied to the value of the land, which varies considerably from one location to another. In November 2006, the Boston Globe reported that an anonymous buyer purchased an open-air parking space in the ritzy neighborhood of Back Bay in Boston for a quarter million dollars.

Environmental issues

The vast majority of vehicles in circulation carry their own power source in the form of liquid mineral fuels. These minerals containing carbon or hydrocarbon are formed under intense heat and pressure inside the Earth's crust from fossilized remains of plants and animals. This process takes millions of years. But when burned, these minerals produce significant amounts of energy, and that is their great value. Cars and trucks and many other forms of transportation use some kind of engine (typically gasoline or diesel internal combustion engines) to convert the energy stored in these minerals into kinetic energy and thus move the vehicle.

However, the burning of fossil fuels generates large amounts of carbon dioxide and also in smaller quantities nitrogen oxides, sulfur dioxide, sulfuric, carbonic, and nitric acids, some radioactive materials, to name a few.

The exaggerated use of fossil fuels has two big consequences: the amount of elements released into the atmosphere is much greater than what can be absorbed by natural processes, and makes fossil fuels a non-renewable energy source because reserves are quickly being depleted much faster than new ones can possibly form.

Carbon dioxide is one of the greenhouse gases, which have been now widely accepted as responsible for the process known as global warming.
The burning of fossil fuels produces around 21.3 billion tons (21.3 gigatons) of carbon dioxide per year, but it is estimated that natural processes can only absorb about half of that amount, so there is a net increase of 10.65 billion tones of atmospheric carbon dioxide per year [8]

Fig. 2.8

Smog cloud in Los Angeles, CA

Just fuels used for transportation purposes alone contributes to 19.6% of the carbon dioxide produced by humans (ranked third after power plants with 29.5% and industrial processes with 20.3%) [9].

Solving problems

While these environmental problems are of utmost importance, it is expected that new technologies will provide a solution in the short term. Besides the growing concern in the population to create a sustainable world, there are substantial investments in research for alternative energy sources, because the availability of fossil fuels is extremely limited and their days are numbered. In the last 10 years, car manufacturers have put into production cars with engines that consume half the amount of gasoline to travel the same distance.

This is clearly a step in the right direction, but more fuel-efficient engines do not help city officials with issues of congestion, parking and all the associated problems described before. In fact, this is one of the most heated discussions all over the world, and most major cities have attempted some kind of solution to these challenges. There are three basic approaches.

If space is still available, the most obvious solution, naturally, is to continue expanding the road capacity, parking spaces and other facilities. If space is already taken, let the market (or use some other politically accepted method) determine the most valuable asset, and simply cut through the urban fabric, replacing less valuable properties with expressways and parking facilities that are big enough to support the traffic.

It has been argued that expanding the road network might lead to savings in travel time and therefore a reduction in fuel consumption and emissions. This method, however, can only go so far. First of all, this approach presents one difficulty that has been extensively documented: greater capacity encourages many more people who have chosen not to travel on roads to start doing so, generating a dependency cycle. This is called "induced traffic". Additionally, cities evolve at a much lower pace than car manufacturers can produce vehicles. But even if the supply was able to expand at the same rate as the demand generated by cars, it would eventually prove futile. The success of a city depends on the ability to offer many resources, jobs and capital in a relatively small amount of land. By continually increasing the supply of roads and parking facilities to meet the demand of cars, key routes and parking lots would replace huge portions of the region, destroying thousands of properties and green spaces; and after all that, much of the space would be empty, leaving a city without resources to offer to its citizens.

Thus, if you can not increase the supply indefinitely, one must reduce the demand. One option in this direction is to simply fully or partially restrict access by car to the city resources. In Beijing, for example, during a two-month period before the 2008 Olympic games, the city government enforced a regulation whereby only half the cars are allowed to circulate on any given day, determined by the car's registration plates. The operation banned cars with odd-numbered license plates one day, and even-numbered plates the next. After the Olympic games were finished, a less severe restriction, which takes cars off the road on one day out of five has been implemented. In Argentina, city officials are studying

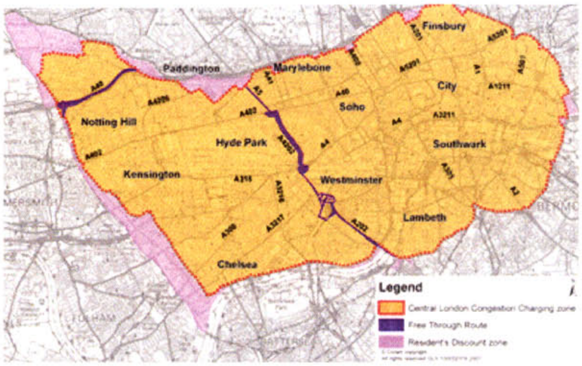


Fig. 2.9
Congestion charge zone in London

the adoption of a similar plan for the entire city of Buenos Aires. Meanwhile, in London, access to the city center through private cars is controlled by economics. Since 2003, motorists must pay a fee to enter those areas in London designated as Congestion Charge Zones. The operation is constantly monitored by close-circuit cameras and vans; and heavy fines are imposed to those who do not pay the fee. Stockholm has also implemented permanently a similar tax program in 2007, encompassing the entire Stockholm City Centre. The pricing is variable depending on the time of the day when the motor vehicle enters the affected area, and is billed monthly to the owner of the vehicle.
A more radical option is to ban automobiles altogether from circulating within certain urban areas, establishing exclusive pedestrian zones. This is not uncommon. Many older European cities have banned or have very restricted access to historic downtown cores. These measures are often highly controversial because they limit the access to a privileged few (dictated by economics, politics or pure luck) or they drastically eliminate the advantages of personal mobility by forcing population to walk or use some method of public transportation.

A third possible approach lies in improving the efficiency of these systems by some kind of overlapping scheme, in the same fashion that real estate gains more profitable ground by increasing the density of a certain area in high demand through multi-storey constructions. This overlapping can be done in space, in time, or both. Parking garages, just like other kinds of buildings, multiplies the available space with a structure that holds the equivalent of a parking lot on top of another. Boston's "big dig" project provides a clear example of such a scheme applied to roads. It re-routed the main expressway running through the heart of the city (I-93) into a massive tunnel, with two main goals: to increase the capacity of traffic flow and its connections and free valuable real estate on the surface. Naturally, these mega-projects require mega-budgets and their implementation takes years of planning and building.

Efficiency can also be increased by a better management of the resources over time, but it requires up-to-date information. These schemes are now much easier to implement through the use of communication technologies and location-aware devices. For example, the city of Santa Monica, CA has implemented a website that displays on a map the number of available spaces in all parking garages. Drivers can check this information and head directly to the most convenient location to leave the car [10]. A more ambitious project has been started in San Francisco, CA. The idea is to deploy a network of wireless sensors attached to the parking meters which will announce what spaces are free at an moment. Drivers in search of parking will receive have this information displayed on a map in their PDA or internet-enabled cellular phones. The system might even allow them to pay for parking through the system directly, without the need to return to your car to add money. The system, working in combination with traffic monitoring systems, will be able to provide information to city officials the current status of the physical network and allow for a dynamic pricing scheme. In other words, when the demand is high, few spaces are free and congestion occurs, the price of parking would go up accordingly. [11]

Fig. 2.10

Central Artery project in Boston, MA

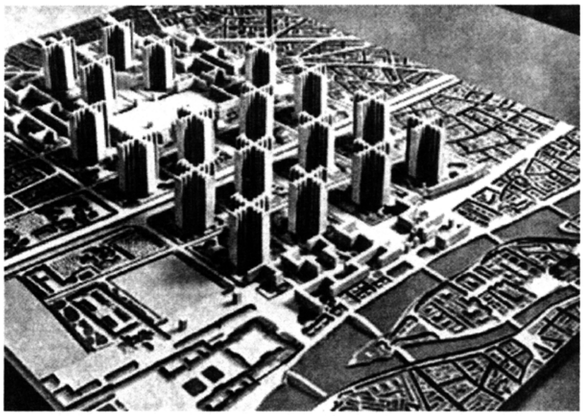
Precedents

Many of the issues brought up by the presence of the car became evident quickly, and a number of solutions were proposed to adapt urban life to the new machine. For instance, in 1931, the New Yorker architecture critic Lewis Mumford, a harsh opponent of urban sprawl, hoped that highways would also create a new kind of city. Mumford and MacKaye's vision of the city is embodied in a plan for the city of Radburn. This city would be formed from superblocks, where residences are turned inward toward a communal park, while automobiles and roads are give access to the rear of the homes. (Fotsch 2005)

Le Corbusier, arguably the most influential architect of the 20th century, was fascinated with the automobile and in his prototypical Ville Savoye, he incorporated the car as a fundamental element of modern living. In his concept for "Radiant City" in 1933, he also designed superblocks and separated pedestrian from vehicular traffic. These superblocks grouped residential buildings (in high density towers) with commercial and other facilities linked by pedestrian areas. These blocks were all surrounded with large green spaces, and restricted the car to a network of major roads. Le Corbusier criticizes supporters of suburban development for the time wasted commuting to the city so his transportation systems were formulated to save the individual time. Thanks to its compact and separated nature, transportation in the Radiant City was meant to be quick and efficient. (Le Corbusier 1967)

Frank Lloyd Wright presented his version of the future city in 1935 with his urban development concept named "Broadacre city" also with a network of elevated highways. Wright, as many others, saw the automobile as a liberation, which allowed people to leave crowded areas and live wherever they wanted. In Broadacre City, almost

Fig. 2.11
Radiant City, by Le Corbusier

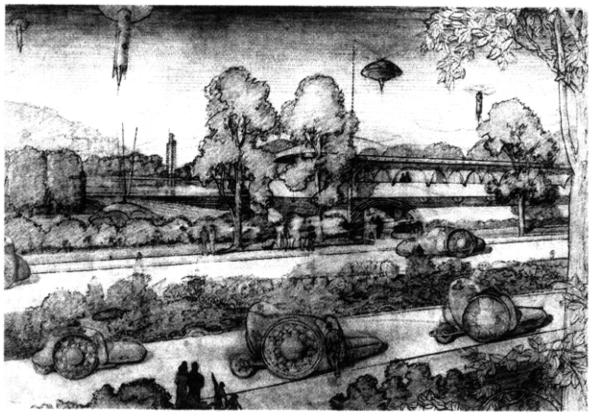


all transportation was limited to the automobile, with commercial and passenger vehicles having their own dedicated routes, and pedestrian were confined to one acre plots where the population lived. He also imagined cars would have a much better design than the trends followed by the automotive industry at that time: "The present form of the motorcar is crude and imitative compared with the varied forms of fleet machines, beautiful as such, manufacturers will soon be inclined or be soon compelled to make". (Margolius 2000)

One of the most influential unbuilt urban visions of the future was exhibited at The New York World's Fair of 1939. "Futurama", designed by Norman Bel Geddes and sponsored by General Motors, featured a network of speed-oriented highways coming from all sides allowing free flow of private vehicles through all parts, at different levels. Interestingly enough, many of the concepts depicted in Futurama were later implemented in the Interstate Highway Act of 1956, and are included as a precedent in the Federal Highway Administration official information web site. [12]

These utopias offer at least some very interesting visions, and while the

Fig. 2.12 and 2.13
Broadacre city, by Frank Lloyd Wright



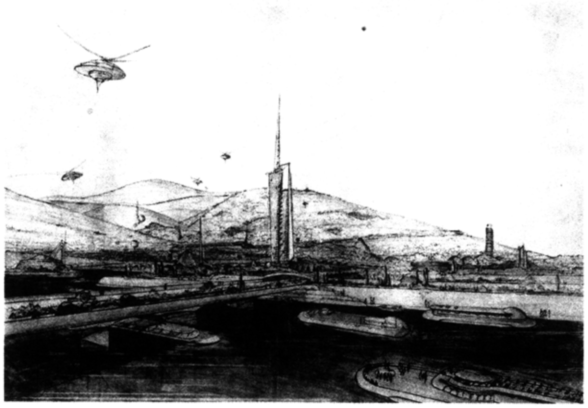


Fig. 2.14 and 2.15
Futurama by Norman Bel Geddes

actual implementations of an automobile-based society may appear much more mundane, there are still some clear points of convergence. The configuration of the garage became a real design problem for residential architecture. Frank Lloyd Wright was one of the first architects to include an open-air carport for the car in his Usonian houses. The automobile became a symbol of status too, so its place in relation to the dwelling was not unimportant. Drummond Buckley in his paper "A garage in the house" points out that the editors of Architectural Record in 1920s boldly claimed that the garage "should be considered the main entrance to the house", and included a diagram to illustrate their recommendations for proper placement. (Wachs, Crawford 1992)

Another less exciting design sparked by the automobile is the drive-in market, which quickly gained the attention of real estate developers, retailers, planners and architects. Supermarkets and shopping malls grew from this type, greatly expanding in size and focusing their configuration internally; but at the same time, the presence of the car was relegated to the residual space for the parking lot, rather than an integral component of the design as in the original drive-in markets

Some American cities turned to the City Beautiful movement, which encouraged the presence of the automobile by building formal grand boulevards on the model of Baron Haussmann's Paris. When City Beautiful planners held a national conference in 1915, the overwhelming consensus was that the car would solve most urban problems. Probably the most notorious example is the McMillan plan which re-designed the monumental core of Washington, D.C. to commemorate the city's centennial and elevate the reputation of the city to that of European capitals of the time. The auto-loving business leaders who sponsored City Beautiful plans wanted to drive to work through imperial vistas, rather than crowded streets. (McShane 1994)

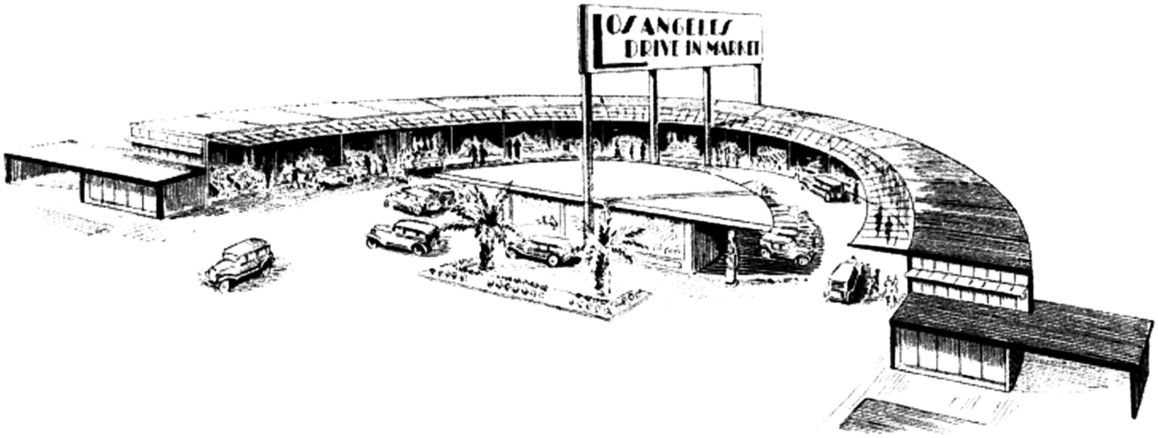


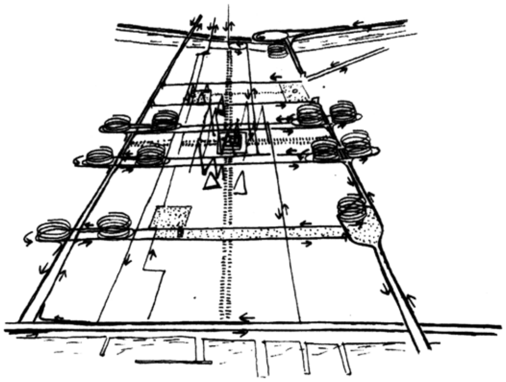
Fig. 2.16
Drive-in market by Richard Neutra

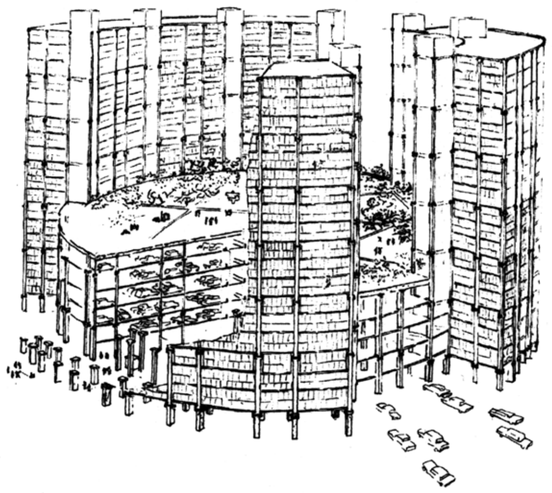
After the war, automobile design shifted to more affordable products to expand the market, and so the parking garage as an architectural type proliferated in the U.S. and Europe. As part of the series of studies for the redevelopment of his home town, Louis Kahn presented the plans for Philadelphia's traffic and street patterns, in which he separated the slow and fast-moving traffic on alternating streets. The studies also included schemes for parking in cylindrical or spiral structures in the core of mixed-used buildings, with an outer layer of offices, shopping and residential units. The city center itself was a pedestrian area protected from the car by walls and these parking towers. (Brownlee 1997)

The relationship between architecture and the car was also the inspiration for American architect Bertrand Goldberg, who designed the iconic Marina City towers in Chicago in 1959. The residential complex consisted of two cylindrical towers with the first 20 storeys dedicated to the automobile and 45 floors of residential units on top. Parking was arranged on a continuous spiral ramp around the central core, which houses vertical circulation and utilities. Goldberg's intention was to eliminate the concept of the street inside the complex, so the towers were arranged on an open plaza at the base, with restaurants, a health club and recreational facilities, where people could wander around as they chose.

In 1967, Paul Rudolph working under the commission of the Ford Foundation presented his vision for the Lower

Fig. 2.17 and 2.18
Studies for Philadelphia by Louis Kahn





Manhattan Expressway. His radical concept consisted of a continuous linear megastructure made of stepped high-rise multi-function buildings. The design was angled to allow for natural light and excellent view and supported with roof gardens, all linked through the monorail and expressway route as the bottom layers. (Monk 1992)

Archigram's Drive-in Housing project took integration with the automobile one step further, literally merging car and building into a single hybrid structure. The radical idea was made of a number of mobile and static containers with folding structures and inflatable skins that could be plugged into service units to form homes. The car, also part of the structure, was a short-range bodyless vehicle, consisting of a tubular frame chassis floating on an air cushion. Michael Webb and David Greene argued that the only real difference between clothing that individuals wear and a car or a house is just "one of size" (Cook 1999; Sadler 2005).

Christopher Tunnard and Boris Pushkarev's book "Man made America" of 1963 is noted as one of the first to explain the role of the automobile in the decline of urban city cores and the expansion of suburbia. The second part of the book deals with the morphology

Fig. 2.19 (above)
Marina City, Chicago, IL by Bertrand Goldberg.

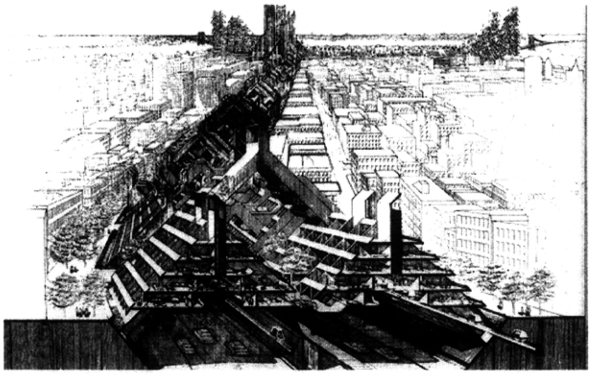


Fig. 2.20 (left)
Lower Manhattan Expressway by Paul Rudolph

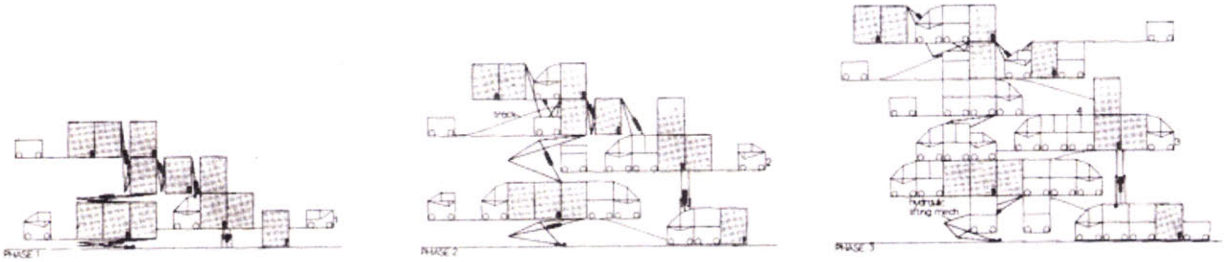


Fig. 2.21 (above)
Drive-in housing project, by Archigram

and visual principles of low-density housing; suggesting aesthetic improvements by incorporating concepts of landscape design. In turn, the third part called "The paved ribbon" addresses issues for highways, and their interest in the driver's perception as a sequential experience. (Tunnard 1963)

Another attempt of integrating the driver of automobile into the urban

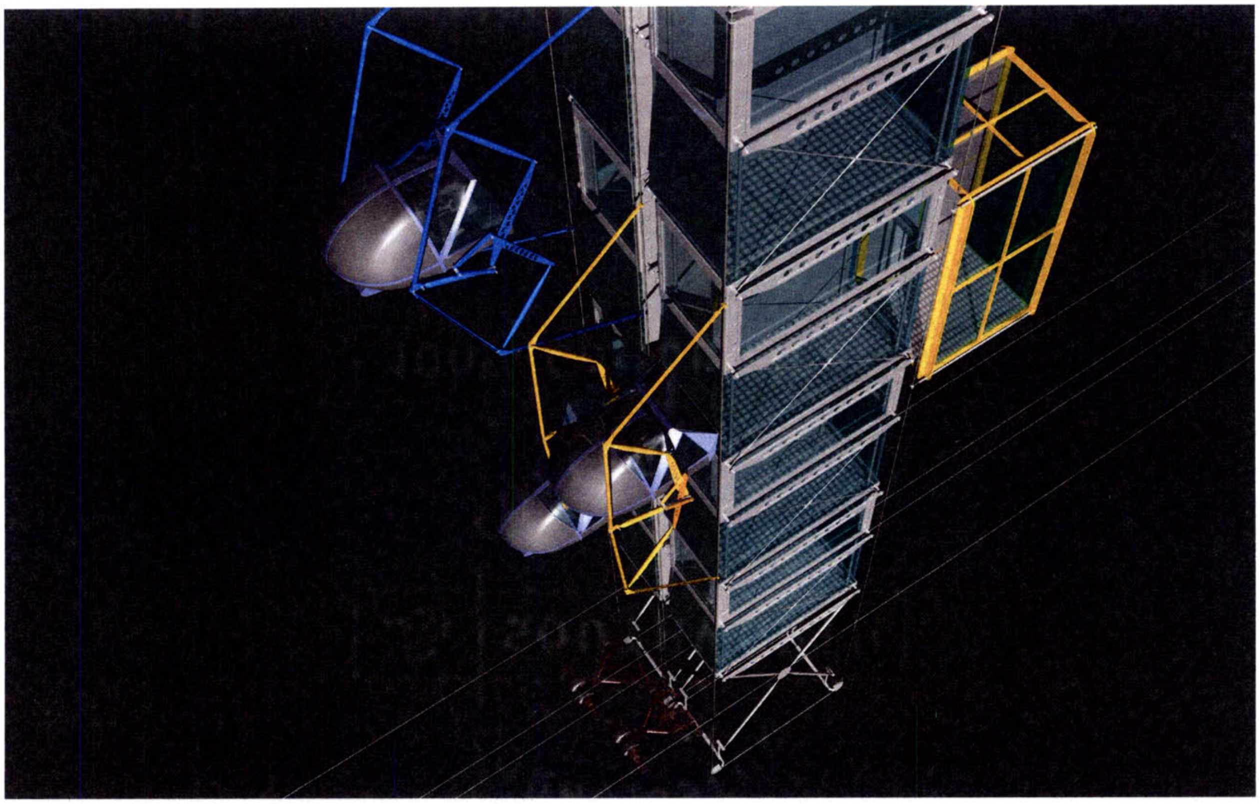
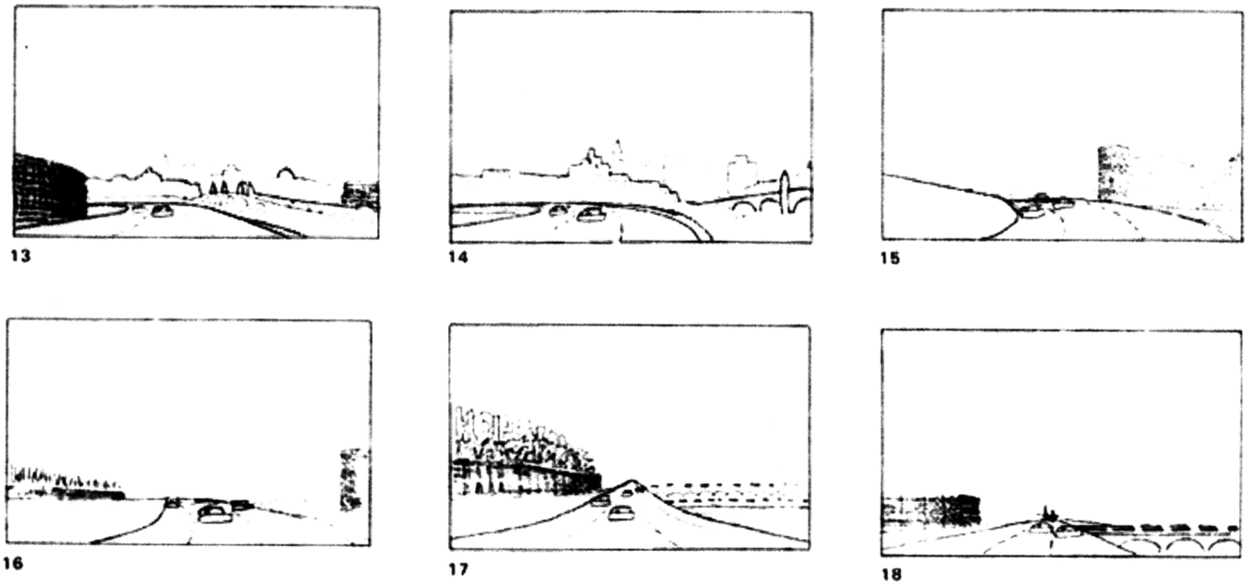


Fig. 2.22 (below)
Drive-in house by Michael Webb, illustration by Takehiko Nagakura.

design considerations can be found in Kevin Lynch, D. Appleyard and J.R. Meyer's monograph "The View from the Road". Their work, published in 1964 while working at MIT, focuses on the aesthetic qualities of the highway landscape, and how it can be considered as art. "Even on highways whose primary function is the carriage of goods and people, visual form is of fundamental importance (…). The view from the road can be a dramatic play of space and motion, of light and texture, all on a new scale (…) making our metropolitan areas comprehensible" (Appleyard, Lynch, Meyer 1964)

In 1991, Joel Garreau, a journalist for the Washington Post, wrote another book highly regarded as influential in contemporary urban design titled "Edge City". In it, Garreau describes the formation of polycentric cities, a new urban phenomenon that appeared as a result of the increasing vehicular traffic gridlock in metropolitan areas. These new urban centers appear usually at the intersection of major highways and have changed to accommodate more commercial and office space than

Fig. 2.23
The View from the Road, by Kevin Lynch, D. Appleyard and J.R. Meyer



bedrooms. The implication is that many commuters from the suburbs are not necessarily driving to the downtown area for work, but just beyond their place of residence, as in the case of Silicon Valley, south of San Francisco. The kind of urban settlement that Garreau describes in "Edge City" is clearly impossible without the presence of the automobile. (Garreau 1992; Gosling 2003)

The New Urbanism movement was born in the early 1980s, partially as a reaction to the negative effects of urban sprawl, fundamentally trying to achieve higher densities, and a walkable town center of mixed commercial and residential uses. Car garages are moved to the back of the houses, and served by alleys, and houses emphasize the re-discovery of the front porch (Calthorpe 2001). However, some of the most notable examples of New Urbanism in the U.S., such as Celebration and Seaside were built on previously open spaces, and for the most part relied on the automobile as a means of transportation, making them essentially not too different from suburbia, and drawing strong criticism.

In the late 1980s, the concept of Sustainable Transport came to light also

Fig. 2.24
Celebration, FL

as a reaction to the major faults in transportation policy of the 20th century. The Ministry for the Environment in New Zealand states that sustainable transport is "about finding ways to move people, goods and information in ways that reduce its impact on the environment, the economy, and society" [13]. It encourages the use of transit, walking and bicycling or other modes that can use energy efficiently, and contributes to the planning of cities to create environments to facilitate these activities.

New mobility is another movement closely related to Sustainable transport, which challenges some of the practices in urban design that have favored the development of urban sprawl, especially concentrating on how to get around the city. Both are especially sensitive to the two largest urban problems derived from the excessive use of cars in cities: congestion and pollution.

Transit-oriented development is one of the strategies of urban design with the purpose of maximizing the access to public transportation. These developments consist in higher densities areas clustered around a rail terminal, subway stop or bus station, with progressively lower densities spreading from these centers. Although this is a reasonable approach, transit is incapable of matching the flexibility offered by the automobile, so it can hardly be regarded as the ultimate solution and replacement for the car. Ralph Gakenheimer notes that with our current problems for mobility, environment, equity and economic development on the agenda, decisions about transportation have become extremely complicated. (Rodwin, Sanyal 2000)

Notes

[1] U.S. Census Bureau and U.S. Department of Transportation (US DOT)

[2] U.S. Department of Labor. Consumer Expenditures in 2002 (Report 974). February, 2004. http://www.bls.gov/cex/csxann02.pdf.

[3] U.S. Department of Transportation, Federal Highway Administration, Our Nation's Highways 2008, Publication No. FHWA-PL-08-021 Washington D.C., 2008.

[4] U.S. Department of Transportation, Federal Highway Administration, Our Nation's Highways 2008, Publication No. FHWA-PL-08-021 Washington D.C., 2008.

[5] Urban mobility report 2005 - Texas Transportation Institute, The Texas A&M University System, 2005

[6] Research and Innovative Technology Administration (RITA). U.S. Department of Transportation (US DOT).

[7] National Household Travel Survey. http://www.bts.gov/programs/national_household_travel_survey/

[8] US Department of Energy on greenhouse gases. http://www.eia.doe.gov/oiaf/1605/ggccebro/chapter1.html. Retrieved on 2007-09-09.

[9] http://en.wikipedia.org/wiki/File:Greenhouse_Gas_by_Sector.png

[10] http://parkingspacenow.smgov.net/

[11] New York Times. http://www.nytimes.com/2008/07/12/business/12newpark.html

[12] Federal Highway Administration. http://www.fhwa.dot.gov/infrastructure/rw96e.htm

[13] New Zealand Ministry for the Environment http://www.mfe.govt.nz/issues/transport/sustainable/

car trouble

an outdated set of design premises

To understand the nature of the problems presented by the automobile in the scale of its context, it is necessary to know its origins and development at least in terms of its configuration.

The car has obtained such a strong presence in our culture that its concept is extremely easy to identify for almost anyone. However, when one starts to explore its history and evolution, boundaries get blurred, as it happens with any term. For example, it is implicitly accepted that cars have four wheels, so does a three-wheel vehicle classify as a car? And what about a two-wheeled vehicle? should the latter be considered a motorcycle instead? Or does it need to have a covered passenger compartment to qualify as a car?

These questions are especially relevant when one has to trace back its history. Most historians and car enthusiasts seem to agree that the car as such was officially invented in Germany in 1886, when Benz and Daimler incorporated an internal combustion engine into their three and four-wheeled machines (respectively).
It is important to note, however, that

before the internal combustion was sufficiently developed for this task, there had been a number of successful attempts to move a carriage with a steam engine. These were nothing more than a carriages that would normally be pulled by horses (hence the concept of a "horseless carriage"). The first one seems to date to 1796 in France, with Cugnot's wagon, which was specifically thought as a military tricycle to move artillery. Eventually, the considerable size required for external combustion engines would make them better suited for larger transportation means, such as locomotives and ships. Steam cars became popular in France and by the end of the 19th century, racing had become a fairly organized activity with the sole purpose of achieving the greatest speed. Electric traction also participated in these races and gained considerable success since the it employed the technology for existing streetcars. This was especially true in the United States and by 1894, New York already had about 2000 electric taxis in circulation. (Belli 2007). These electric cars were also popular among ladies, since the starting handle of the internal combustion engine presented a physical challenge. Furthermore, electricity was already available at homes, but gas stations did not exist yet, and fuel needed to be purchased in cans from drug stores. The disadvantage of electric cars, of course, was the battery capacity, which greatly limited the car's range between charges to short trips, and back then short trips were the exception. Most people lived in rural areas and mobility in the city was covered by a combination of walking, bicycles and transit systems (streetcars, trolley buses).

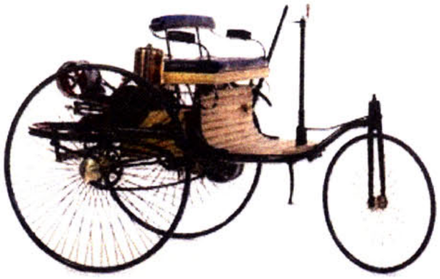


Fig. 4.1.
Karl Benz Patent Motorwagen, 1886

The point of which one constituted the first car is not relevant for this discussion. What is important is to understand that the car as such did not magically appear in an eureka moment, but it was a natural progression from other contemporary technologies. For pragmatical purposes only, this analysis of the evolution of the shape of the car starts around the time when horses pulling the carriages were replaced by a mechanical device on board. Naturally, the form (and function) of these first cars was derived from what was common in those days. Just like a carriage, many of these first cars required a professional to drive and maintain the machine. Some were lighter, with just a set of seats and a small cargo space on the chassis, while others had a fancier cabin for passengers, protected from the elements.

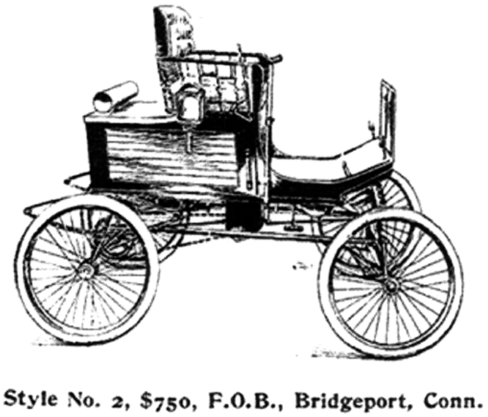


Fig. 4.2. (above)
Steam-powered Locomobile, 1901

Fig. 4.3. (right)
Riker electric vehicle, 1900

All elements were borrowed from the horse-drawn vehicle. For example, originally the position of the driver was high because he needed to see over the horses, and this was repeated in the first cars even if the horses were not there. Other components were also carried without much change, such as oversized wheels and large mudguards, and hanging lanterns.

It has been extensively argued that Karl Benz's contraption constitutes the first "true" car, since it was an independent design with an original configuration rather than a converted carriage with an engine in place of horses. But no innovation comes out of nowhere; instead, his three-wheeled design utilized a chassis frame made with tubes for bicycles, and its wheels were provided by Kleyer of Frankfurt, founder of a bicycle manufacturing company.

Fig. 4.4.
Fiat 3.5 HP, 1899

The specific details of where inspiration came from do not matter for this argument. Slowly, early in the 1900's the shape of the car evolved toward a configuration that would gain widespread adoption and last through time until now. The engine was mounted longitudinally in the front of the vehicle, and encased in a box for weather protection, called the "capot". This would allow to fit larger engines with more cylinders just by extending the length of this box (the hood). The radiator, which required direct air intake, became the adopted cooling technique and an emblematic feature of the shape of cars to come.

The adoption of aluminum and steel panels was another major step, since they were much easier to shape, lighter and easier to work. Metal panels began to be applied to the wooden structure, and the first metal sheet-metal panels started to define the overall exterior shape of the car while hiding the intricacies of its mechanical components.

Within a decade, the shape of cars evolved into a much clearer and identifiable definition: the torpedo form. The torpedo body represents a major point in the history because it treats the vehicle as a single volume for the first time: the engine, the passenger compartment and the cargo space (in that order) follow a single line from beginning to end, while the four wheels stick outside this volume and are covered with styled mudguards. The position of the driver and passengers is now much lower, and the body follows the lines of the box containing the engine in the front. A fold-down windshield (which was nothing more than a screen held by thin frames), a hood and new headlights (replacing the lanterns) complete the overall design.

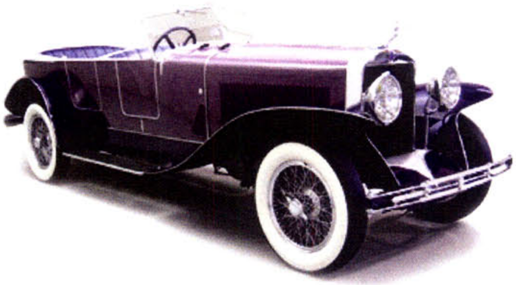
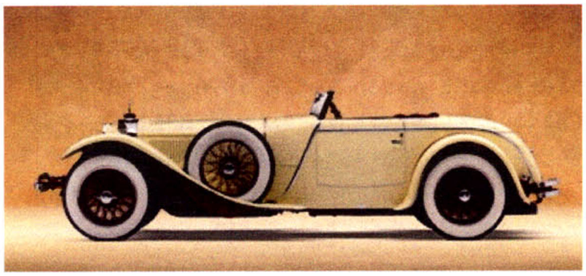


Fig. 4.5. (above)
Isotta Fraschini, 1927

Fig. 4.6. (right)
Mercedes torpedo roadster, 1928



The torpedo body rapidly influenced the design of many variations, and coupes, limousines and closed vehicles adopted these principles too. Between 1920 and 1930, the market notably shifted with the popularity of the closed cabin for passengers and drivers. Closed-car designs went from 10% in 1920 to 98% of sales in 1929. By then, motor cars effectively replaced horse-drawn

carriages. These new vehicles had achieved enough comfort, reliability, speed and most importantly they had been made accessible to a wide market, largely in part to the industrialized processes started by Henry Ford for his famous Model T.
This is also the time when countless variations of car models were offered to the public. in 1926, the British Engineering standards sought to unify types and concluded that there were 26 different body styles for automobiles, which included categories such as "two-seater", "coupe", "coupe cabriolet", "saloon", "enclosed landaulette" and "open touring", to name a few. However, categorizing infinite variations proved an impossible task, and while other countries attempted similar classifications, no universal convention was adopted, and labels remained the subject of discussion for historians as well as enthusiasts.

The next big step in the overall design of the automobile form was the adoption of aerodynamic principles. In 1921, Paul Jaray presented his patent for a streamlined car body:

> *The lower part of the body has the form of a half streamline body and covers the chassis with the wheels, the engine compartment and the passenger compartment. The lower surface is even and runs parallel to the floor space. On this main part a substantially narrower streamline body is set, which is carried by a framework-like construction.*

Right angles started to change and the vertical line of the radiator was tilted, more rounded and continuous with the main volume of the engine. Similarly, the windshield plane was angled backward, communicating the top line of the hood with the roofline. The sides of the front volume created

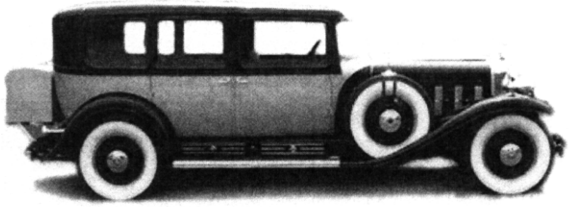
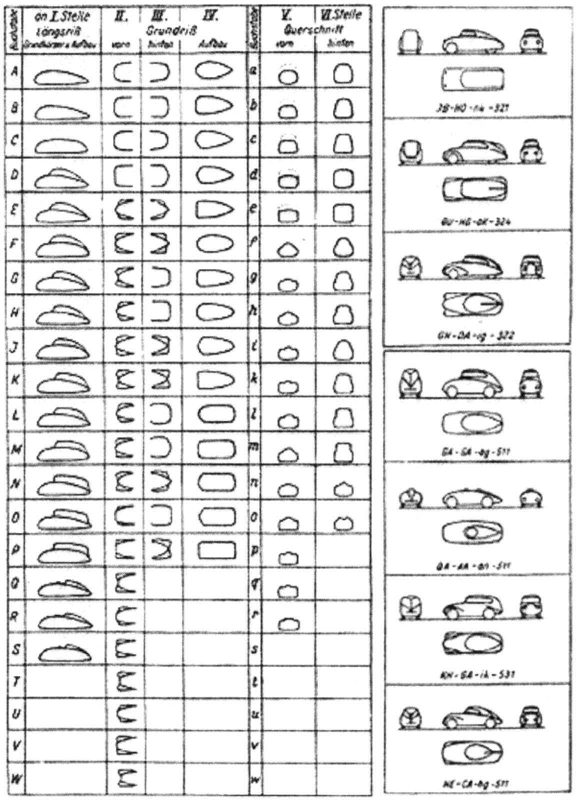


Fig. 4.7. (above)
Cadillac V16 Imperial Divider Glass Limousine, 1930

Fig. 4.8. (below)
Paul Jaray patent, 1921 [1]



‘waist’ lines that continued into the lower line of the windows, while the rear was lowered back into the ground, creating a so-called “drop shape”. Headlights and other protruding elements became integrated, following the lines and surfaces that define the new volume, which also extend to the mudguards, effectively integrating the four wheels into the overall volume of the automobile.

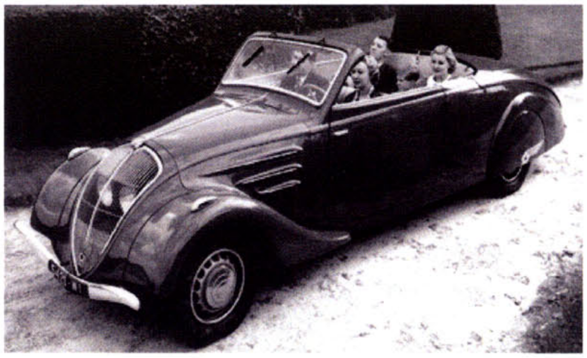


Fig. 4.9. (right)
Peugeot 402 Eclipse, 1937

Much of this process was driven by intuition more than actual physical experimentation, and some concepts would not be tested until many years later, but it did not matter.
These new principles were applied to luxury cars as well as to more affordable vehicles that introduced the idea of mass mobility in the United States and Europe, with such notable

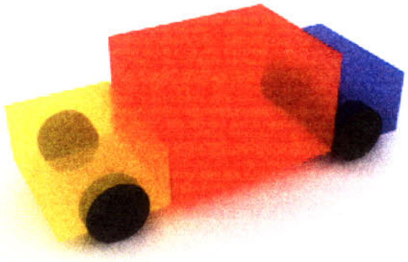
Fig. 4.10. (right)
Fiat 500 A Topolino, 1937

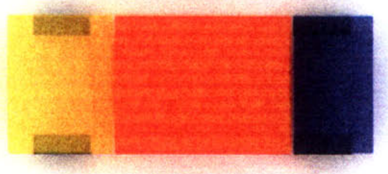
examples as the Fiat 500 Topolino, the Citroen 2CV and the Volskwagen, which would eventually achieve enormous commercial success and leave a mark in popular culture.

While these new lines are an important step in the progression of the car form, they represent the consolidation of the underlying structure that cars would have until the present day. In fact, many of these designs have survived or have been revived with minor cosmetic updates. Ferdinand Porsche, one of the designers of the Fiat 500 Topolino would later create the sports car that bears his name, which has remained largely unaltered from the exterior, while its mechanical parts and interior are constantly renovated. Similarly, Volskwagen re-launched its Beetle model in 1998 and Fiat announced the new 500 in 2007, which mostly relate to the previous versions in its name and the exterior styling.

Fig. 4.11 (above)
Volskwagen Beetle, 1938

Fig. 4.12 and 4.13 (below)
3-box configuration for automobile design

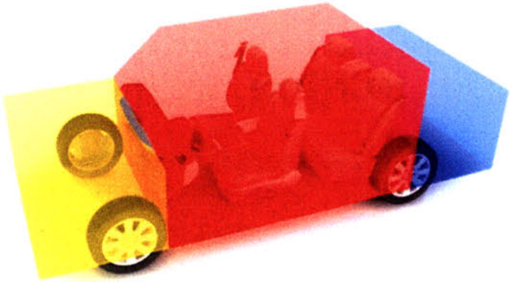




Current automobile configuration

Despite the evolution and refinement in the external form, the underlying design of the automobile has changed very little since the engine was mounted at the front by Panhard et Levassor in 1891. The majority of cars used for personal mobility respond to a simple volumetric arrangement resulting from that original configuration.
If a car were to be analyzed under architectural terms, the program of a typical automobile has three basic components: the drivetrain, the passenger space, and the storage compartment. Generally speaking, each of these units are separated from one another for functional reasons: the drivetrain is occupied by loud and dirty machinery, which runs at high temperatures and produces undesirable gases and fumes; while the cabin needs

Fig. 4.14. (right)
Standard automobile seating arrangement



to offer a comfortable and protective space for the passengers. The storage unit, obviously, does not require the same levels of safety and comfort as the main cabin, so it is usually a separate compartment. The shape of the automobile, therefore, responds to this three-volume configuration: one volume for the drivetrain, one for the passengers, one for storage, all of them joined and mounted on a horizontal frame that connecting the four wheels (chassis). The term "sedan" or "saloon" refers to this body style.

From the top view, cars respond to a more or less rectangular shape with its four wheels mounted approximately at each corner. The overall exterior configuration is symmetrical on the long axis, so left and right sides are mirrored. Its width has very little variation, at approximately 1.5 meters as a consequence of the necessary room for two people facing the main direction of movement. The interior is also symmetrical, except for the driving controls, which are located in the front row, and only on the left of the right side of the vehicle, which varies according to the country.
From the side view, the bottom of the main volume of the car is roughly aligned with the center point of the wheels (axis of rotation).
Most automobiles show some kind of

differentiation between the front section and the back, with also some variation in its total length. Excluding more specialized vehicles such as sport utility vehicles (SUVs), the overall height is a result of the space required for a seated person, usually under 1.5 m.

From the front view, the appearance of a car offers the less variation, since it is largely a simple extrusion of the profile defined on the side view.

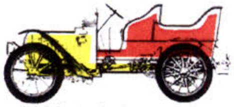
Naturally, the most common variation to the basic three-volume scheme is a two-volume configuration, in which passenger and the cargo space are combined into a single unit, since the requirements are more or less compatible. Sometimes these two compartments are one single unit in the interior as well as the exterior, and are divided to different degrees, but they usually have separate access doors. Hatchbacks, liftbacks, station wagons and some minivans fall into this category.

Finally, there are also some examples of single-volume cars. Of course, these generalizations are not so clear-cut, especially in recent times that have popularized more streamlined body shapes and replaced hard lines with curves blending from one section of the car to another. This has led to many different term variations, such as semi-notchback or fastback sedans.

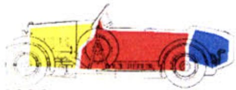
However, the drivetrain volume is still largely positioned in front of the car, then followed by the passenger space in the middle and the storage compartment in the back. Some notable designs throughout history have inverted this scheme by placing the engine at the back as in the case of the 1938 Volskwagen Beetle, although this was later modified for the 1998 version. The space required by the wheels is subtracted from the front and rear volumes.

Since the drivetrain and the storage unit are attached to the front and rear,

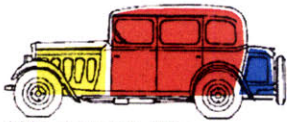
Fig. 4.15. (right)
Evolution of car configuration



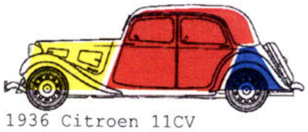
1903 Daimler Mercedes



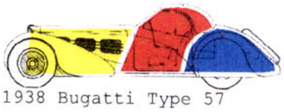
1926 Bugatti Type 40



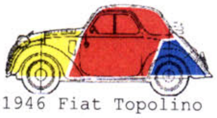
1932 Peugeot 301



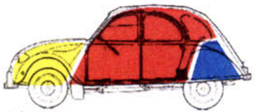
1936 Citroen 11CV



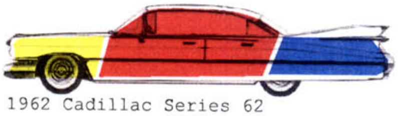
1938 Bugatti Type 57



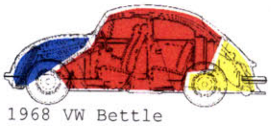
1946 Fiat Topolino



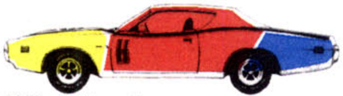
1948 Citroen 2CV



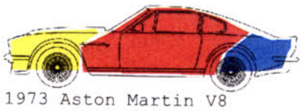
1962 Cadillac Series 62



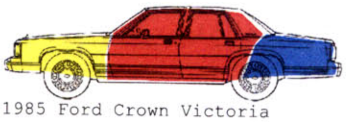
1968 VW Bettle



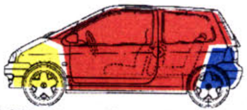
1971 Dodge Charger



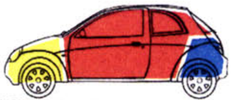
1973 Aston Martin V8



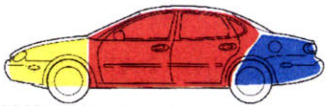
1985 Ford Crown Victoria



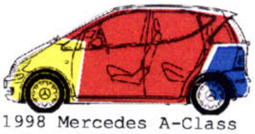
1993 Renault Twingo



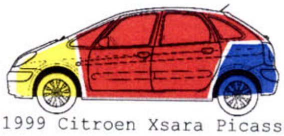
1997 Ford Ka



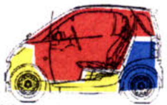
1997 Ford Taurus



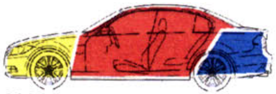
1998 Mercedes A-Class



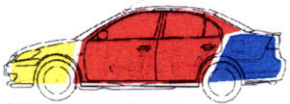
1999 Citroen Xsara Picasso



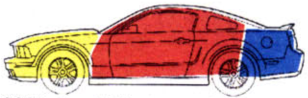
2002 Smart ForTwo



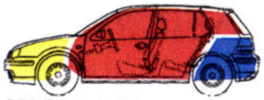
2004 BMW 3 Series



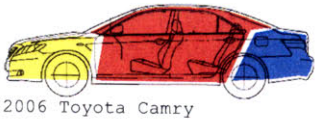
2005 Honda Civic



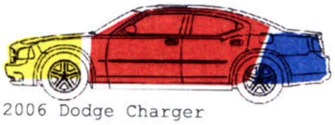
2005 Ford Mustang GT



2006 VW Golf (Mk 4)



2006 Toyota Camry



2006 Dodge Charger

the sides of the passenger cabin constitute the preferred method for ingress and egress. The lower half of the cabin, together with its roof and most of the planes enclosing the drivetrain and storage spaces are solid opaque surfaces. The top half of the cabin is transparent to offer the driver with a field of view as large as possible, since the driver's vision is the primary input method of contextual information that makes driving possible.

While over the years the automotive industry has been taking into account new aspects into the design of vehicles, such as passenger and pedestrian safety, energy consumption and ergonomics, the relationship between the automobile and its support system (roads, parking, fuel stations – in other words, the city) has been largely neglected. The issues concerning the presence and use of automobiles have almost nothing to do with the features that dominate the design and production (top speed, styling). Other professionals are left to figure out and ensure acceptable solutions for circulation and parking are in place. With more and more cars being manufactured and sold, the burden of providing the necessary roads and parking facilities falls on to city officials and developers.
Donald Shoup argues that planners and cities make parking requirements without taking into account the price charged for it, the cost of construction and maintenance or the wider consequences for transportation, land use, the economy and the environment. Unfortunately, exactly the same can be said about most car designers.

For the most part, automotive design has considered the car as an individual object almost excluded from any other contextual implications. The car has become a design object centered in itself. This image is largely exploited

by advertising campaigns, that show vehicles by themselves, with careful lighting that highlights the geometric surfaces and are completely devoid of any surroundings or immersed in idyllic driving situations such as empty freeways or swiftly cruising through a landscape, conditions that rarely match the reality of trying to find a parking spot in a busy street in downtown. As a matter of fact, that particular situation seems to have been left out of the design premises.
As seen, despite numerous technological improvements since its invention, the basic configuration of the automobile has remained nearly identical to its original design. This would not be a such a big problem if the context in which most cars operate had not changed so dramatically. In the last two hundred years, most of the people lived in rural areas and car were designed as heavy, strong machines to connect somewhat long distances. According to the United Nations, in 1800, only 3% of the world population lived in urban areas, whereas in 2008, that number jumped to 50% [2]. In the United States, in 1900 when the first motor cars were already circulating on the streets, 39% of the population lived in cities and 61% in rural areas [3]. Resources were distributed sparsely across the land, so naturally, trips were longer. People moved to urbanized areas precisely to be closer to all the resources that modern life offers, and in 2005, urban areas held 80% of the population in the US [4].

According to the 2001 National Travel Household Survey, the average American driver drives 29 miles each day. 88% of drivers in the US travel less than 80 miles daily, and for over 40% of drivers, their total travel distance (usually including a round trip) is less than 20 miles. [5]

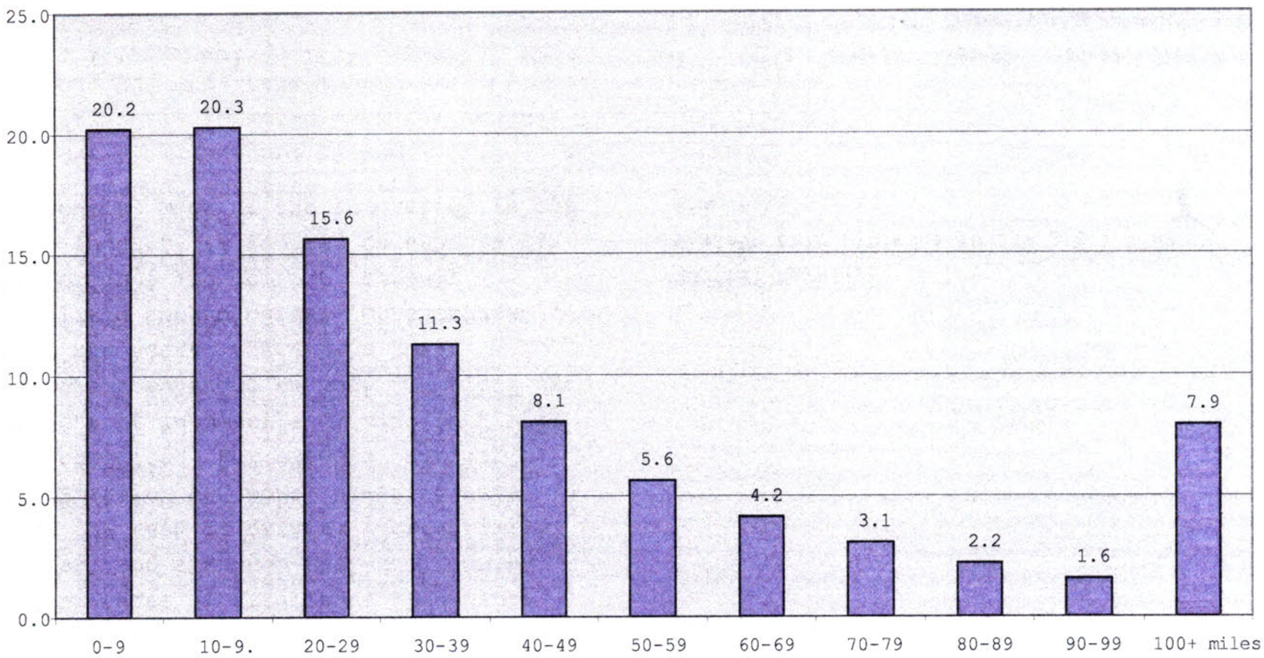


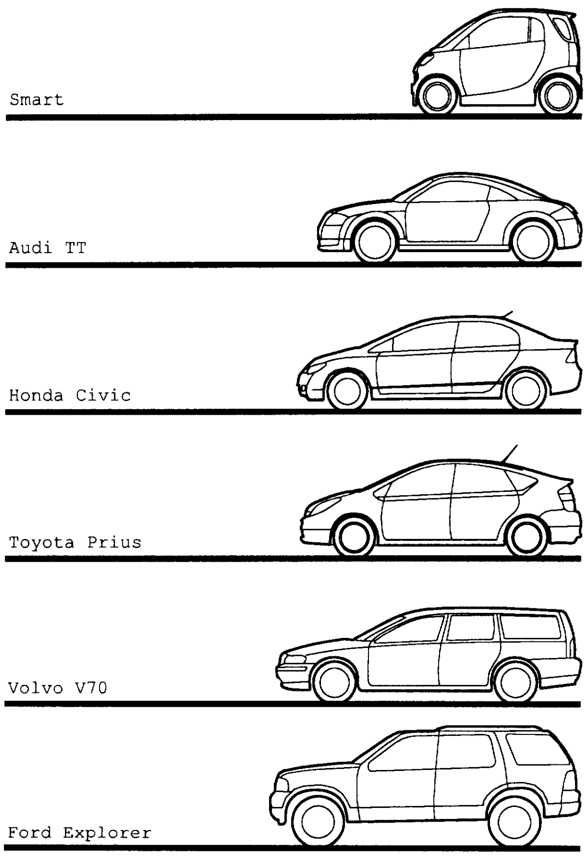
Fig. 4.16.
Average trip distance in the U.S., 2005
Source: NTHS [5]

Currently, most of the innovation in the auto industry is focused on aspects of performance and comfort, through localized technological improvements. Over the years, there have been important advances in many functions and aspects of automobile driving that must be recognized. For example, automatic transmission and power steering have made the task of driving substantially easier, and although they still carry higher rates of fatalities than other means of transportation, safety for drivers and pedestrians has significantly improved over the years. Currently, with economic and environmental concerns on the forefront, there is a strong effort to improve fuel efficiency and research in alternative fuel sources.
Excluding these technological improvements, one can argue that consumers have accepted this form of transportation as it was established over a century ago and there have been no major innovations in its configuration. Even in terms of styling -the strongest selling point of

automobiles- the differences between models are subtle yet most important for a public with increasingly discriminating taste. The industry is quick to respond to consumers more concerned with the social status of the automobile than any of its implications as a means of transportation, which helps understand the massive popularity of disproportionate vehicles such as SUVs in dense urban areas. A study by JD Powers and Associates for 2008, indicated that the main reason to choose one car over another is styling at 43%, its price being the second consideration at 40%, and just 13% of surveyed people cited fuel efficiency. Even within the current cultural awareness that pushes the so-called "green" options, only 4% of new car buyers mentioned environmental concerns as a reason to pick one particular automobile. [6]

Without negating the benefits of personal mobility, one must also recognize the incongruence of the current configuration of the automobile. An average car weights around 3000 lbs; if it carries only one person at 150 lbs –as is the case for most of the commuting trips-, the person represents only 5% of the total weight, which means that approximately 95% of the energy required to move forward is spent on moving the car itself. And while there is no agreed method for comparing the efficiency of electric motor and a heat (fossil fuel) engine, it is widely understood that most of the energy generated by the internal combustion engine is lost in transmission and never reaches the wheels. The main reason for this loss is the large number of elements inside an engine moving at high speeds, which generates friction and this energy creates heat. Despite lubricants and coolings, it is estimated that the efficiency of a typical vehicle engine

Fig. 4.17.
Typical current automobile profiles



Class	Manufacturer/model	seats	EPA (mpg)		length (in)	width (in)	weight (lbs)	horsepower	range (mi)
Minicompact	Audi TT	4	23	31	164.5	72.5	2965	200	377
	Smart	2	33	41	106.1	61.4	1808	70	321
Subcompact	Honda Civic	5	26	34	177.3	69	2687	140	382
Compact	BMW 3 series	5	18	28	178.2	79.3	3340	230	381
Midsize	Volskwagen Passat	5	19	29	188.2	71.7	3344	200	444
	Toyota Prius	5	48	45	175	67.9	2932	76	552
Large	Ford Crown Victoria	6	15	23	212	78.3	4129	224	372
Wagon	Volvo V70	7	16	25	189.9	73.3	3527	235	358
Large Pickups	Ford F150	5	12	18	213.1	74.6	4881	248	350
Minivan	Dodge Caravan	7	16	23	202.5	76.9	4483	175	411
SUV	Toyota Rav4	5	22	28	181.9	73	3560	269	367
SUV	Ford Explorer	7	15	21	193.4	84.8	4531	292	400

Table. 4.18.
Typical current automobile specifications

is between 20% and 35%.

Furthermore, engines are now very powerful expensive machines: a typical automobile has over 150 hp and a range of 300 miles. Yet the average vehicle trip length was 9.06 miles in 1995, leaving most of its potential untapped (but paid for). [7]

In the beginning, the motor car was almost exclusive to a wealthy few: the price was high and a full-time chauffeur was also a must. After Henry Ford applied the principles of manufacturing, the automotive industry was born, and despite still representing a major expense, cars were now accessible to a much wider segment of the population. Nowadays, in the US, more than 60% of the households have more than one automobile, meaning there are more specialized uses for cars (one for commute, one for recreation, one for the parents, one for the young, and so forth).

As discussed before, some congestion seems inevitable. But it is also clear that the current situation is exacerbated by the kind of vehicles we are using.

It is widely known that most cars on the road have only one person in them. In 1990, the U.S. Census Bureau reported that the average vehicle occupancy was 1.1 passengers per car, in trips from home to work. The number is slightly better for shopping and other family or personal business (around 1.7 and 1.8 respectively), and 2.04 for recreational trips [8]. In Europe, the situation is not too different. The Scottish government indicates that in 2005/2006, 60% of the trips were done by one person only, 27% with two persons inside and only 12% with more than three or more people in the vehicle. [9]

On top of that, as mentioned in chapter 2, the average automobile spends 95% of its time parked -that is, unused- while there are three other parking spaces unoccupied.

Parking geometrics

The shape of the car responds mostly to a very simple requirement: to move forward. This might sound obvious, but it has at least two important implications when it comes to city transportation: maneuvering and parking.

Except for specialized work vehicles such as forklifts, most cars are equipped with four wheels attached to two fixed axles. This configuration only allows for movement in one direction (forward and backward), so the two front wheels are also capable of rotating a few degrees on its vertical axis (about 30 degrees) which allows the car to gradually change its direction while moving by describing an arc. That is, the car must also move forward even if the driver needs to move to the right or to the left.
The turning radius of a vehicle is the

radius of the smallest circle in which it can turn. Because the wheels are slightly offset from the corners of the body of the car, there are two different values. The most common value is the curb turning radius, which is half the width of a road in which you can make a smooth turn without hitting the curb. The other value is called wall to wall turning radius, which is half the distance between parallel walls where the vehicle can turn.
The turning radius of a vehicle depends mainly on the wheel base (distance between front and rear axle) and the wheel cut of the vehicle (the maximum angle through which the tires turn when the steering is rotated from the center). The smaller the wheel base, the smaller the turning radius, while smaller the wheel cut, the larger the turning radius. The turning radius is related to the maneuverability of the vehicle, and also affects the design of parking spaces and driveways.

Although the technicalities of steering have been improved and modified over the years, this method has been widely accepted and still remains the same as it was in the beginning. While it has proven very convenient for driving forward, it is very cumbersome if the vehicle needs to reverse its direction or maneuver in tight spots (which is not uncommon in busy and narrow city streets). In summary, cars are not fully equipped to negotiate tight situation that commonly occur in dense urban areas, so cities have had to adapt generously their circulations paths to the requirements imposed by the automobile.

Likewise, when it comes to parking, if the parking is not straight ahead or at a 45 degree angle, it can be a difficult task to complete. As a matter of fact, parallel parking next to the curb is widely seen as the most feared section of the driver's licensing exam. When analyzed like this, it does sound strange that cars are not explicitly designed to be parked, which is what they do at the end of every trip and stay there for most of the time. In response to this, some of the newest high-end vehicles have begun to offer a mechanism equipped with sensors that automates the task of parallel parking. On-street parking is somewhat simpler because it depends on the available length of a block, the dimensions of the street and other constraints such as driveways, fire hyrdrants, bus stops, loading zones, etc that might limit the space. But off-street parking has become a major component of the built environment, since most developments are subject to comply with minimum parking requirements set by municipalities and local governments. Donald Shoup argues that current off-street parking requirements in place in most cities are the consequence of a poorly understood activity that has led to disastrous results. Because this proposal focuses on a reconfigured scheme of the car, the procedures for calculating parking demand are not entirely relevant, but the physical dimensions -which directly depend on the kind of automobiles we use today- and layout schemes are.

When it comes to parking layouts in specific situations, some arrangements might be more beneficial than others. However, in general terms, different angles in parking stalls result in approximately the same gross square footage per space. Parking at 90 degrees (in relation to the direction of circulation) provides greater freedom of vehicular circulation, and decreases the conflict between pedestrians and cars. On the other hand, a 90-degree turn is required to park and leave the stall, which results in bigger dimensions for circulation areas.

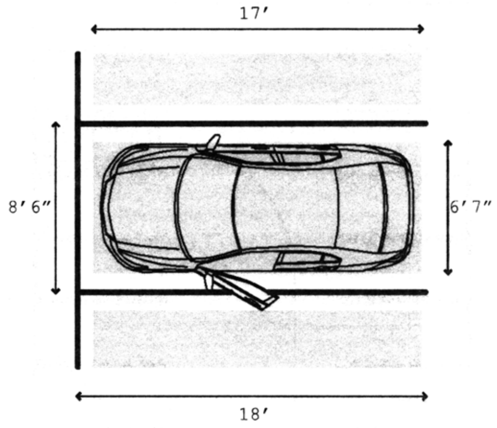
One-way aisles on angled parking stalls facilitates maneuvering in and out of the parking space, and the time required to complete the task is reduced, which translates in smaller delays for other vehicles. Additionally, rear doors can be opened without hitting other cars. However, drivers frequently go the wrong way on one-way aisles, increasing the potential of conflicts with other cars and if they try to park from the wrong direction, the benefits of angled parking disappear.

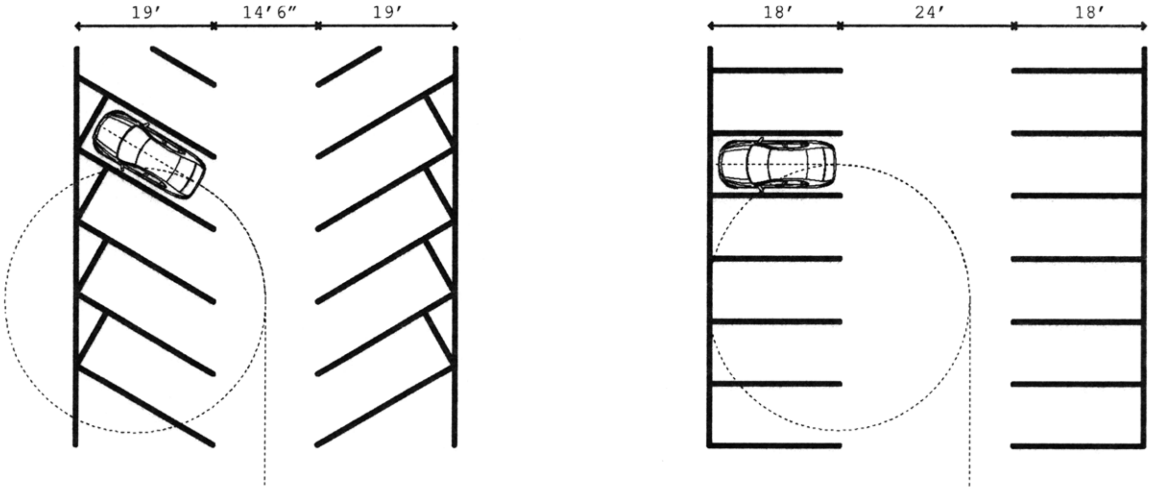
When an automobile door is opened for the driver to get in or out of the vehicle, the design of the hinge mechanism tends to swing open the door to the first stop. Failure to have adequate clearance between parked cars results in dents on the side of the adjacent vehicle. Thus, many car models include plastic side moldings to absorb these impacts.

The size of a parking stall is not only determined by the size of the car but it also varies according in relation to other parameters. For example, places with high turn-over rates, such as banks

Fig. 4.19. (below)
Design vehicle

Fig. 4.20 and 4.21. (far below)
Parking geometrics





Parking Angle	Module	Vehicle Projection	Aisle
45	48'0"	17'8"	12'8"
50	49'9"	18'3"	13'3"
55	51'0"	18'8"	13'8"
60	52'6"	19'0"	14'6"
65	53'9"	19'2"	15'5"
70	55'0"	19'3"	16'6"
75	56'0"	19'1"	17'10"
90	60'0"	18'0"	24'0"

Fig. 4.22.
Module dimensions depending on parking stall angle. (ULI 2000)

and convenience stores, require larger clearances than those with lower turnover rates. Similarly, places with a special demographics (for example places such as elderly people, or hospitals) might also require larger parking stalls. (Chrest 2001; ULI 200)

Still, to determine the required parking space, planners use the requirements of the so-called 'design vehicle', which is based on the dimensions of the 85th percentile vehicle in the range from smallest to largest vehicles. In 1998, Walker Parking Consultants estimated the dimensions of such 'design vehicle' at 6'7" by 17'. (ULI 2000)
The critical elements of parking space dimensions are the width of the parking space relative to the width of the vehicle and the ease of maneuvering the vehicle in and out of the parking space. The interrelationship between aisle and parking space width is such that, within reasonable limits, a wider aisle can permit a narrower parking space and vice versa.
The length, on the other hand, is not affected by higher turnover rates. The gap between a vehicle and a restraint is about 9 inches, which combined with the dimension of the design vehicle results in a recommended length for parking spaces of 18 feet.

Other inefficiencies

Communication technologies are still not well integrated with the automobile, despite huge growth and increasing popularity in the last decades. There are very specific programs with different levels of success. One of the earliest attempts of integration was offered by LoJack, which provides stolen vehicle tracking service through the use of a hidden radio transmitter, registered to a central database. OnStar, for instance, a subsidiary of General Motors, offers to its subscribers navigation aid, emergency services and remote vehicle diagnostic. GPS systems are now widely accepted, but they remain as optional add-ons for most cars, and only high-end models offer integrated navigation systems.

The hypothesis of this work is that most of the problems that the automobile generated are due to an outdated set of premises and an extremely inefficient scheme of utilization. Simplistic measures such as increasing the supply of roads and parking spaces have proved insufficient and sometimes counterproductive, generating even more demand, while disintegrating the urban fabric. The proposed solution must be a series of measures that complement each other to achieve a redistribution in the utilization of resources, so that personal mobility is not sacrificed and waste is reduced to a minimum.

In the next chapters, I will describe the configuration of a new kind of automobile, designed with these objectives in mind. While design is at the center of this dissertation, this is not an exercise in styling, but an attempt to demonstrate that with a number of adaptations in the configuration of the automobile we could achieve a radical impact in our urban environment.

It is easy to understand why numerous studies have concluded that the current situation is simply unsustainable. While technology will eventually provide a solution to all environmental challenges, the problems are all interconnected and require more than one single recipe. The urban impact (even if only measured in economic terms as Professor Shoup has extensively argued) needs to be reversed by a combination of policies, technology and imagination.

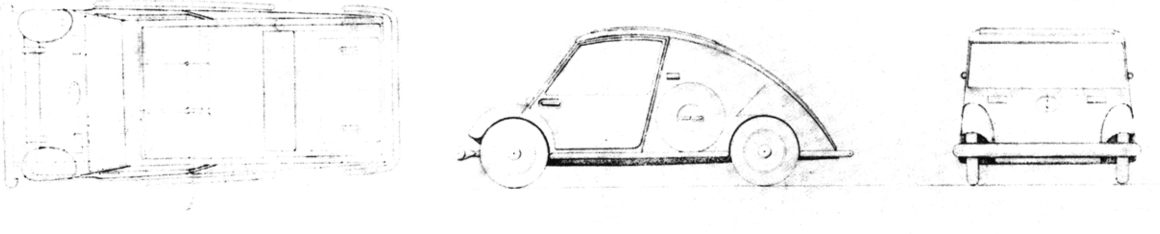
Fig. 4.23. (above)
Citroën 2CV prototype, 1939

Outside the trend

One the first car to truly step out of the tendency in the automotive industry was the Citroën 2CV, designed by Pierre-Jules Boulanger in the early 1930's. At the time, France had a very large rural population and luxury cars were restricted to the wealthy minority. His approach was entirely different. The 2CV [from deux chevaux vapeur, or two steam horses] was an economy car, for two farmers to carry 100 lbs. of potatoes at a speed of 37 mph. Additionally, it had to be rugged to drive through unpaved muddy roads, its fuel consumption had to be 3 liters of gasoline per 100 kilometers (78 mpg) and cost one third of the 7CV Traction Avant. This was an example in which the design premises were relevant for a specific purpose. By 1939 several prototypes had been built and it was ready to go into production, but it was halted with the outbreak of World War II. The vehicle was unveiled at the Salon de l'Automobile in 1948 and went on sale the following year to become a commercial success and an icon in automotive history. (Margolius 2000)

In 1935, Le Corbusier with his cousin Pierre Jeanneret submitted a design for a small vehicle to the competition organized by the Société des Ingénieurs de l'Automobile (SIA). The rules for the competition aimed to produce an affordable vehicle for the people, in a move to expand the market outside luxury

Fig. 4.24. (below)
Voiture minumum by Le Corbusier and Pierre Jeanneret, 1935



vehicles. The drawings for the car, called Voiture Minimum, lacked in technical development but showed an innovative concept which had been studied over since at least 1928. The design was wider than usual, with three seats in the front, a bench in the middle and the rear section destined for luggage and the engine.

Buckminster Fuller is well known for his revolutionary design of the Dymaxion car, but his involvement in car design was extensive. Perhaps one of his most interesting concepts was done in 1943 for a small vehicle to be built after the war, which never reached production. It was called the D-45 and its futuristic egg-shaped body followed the aerodynamic design lines of the Dymaxion at a smaller scale. He proposed a compact car with three twin-wheeled, about 2m wide and 3m long, and capacity for four passengers seated in a single row. Interestingly, each of the three twin-wheels had attached a small five-cylinder gasoline engine capable of 25 hp. The two front engines were used for driving, while the third engine operated

Fig. 4.25 and 4.26
D-45 by Buckminster Fuller, 1943

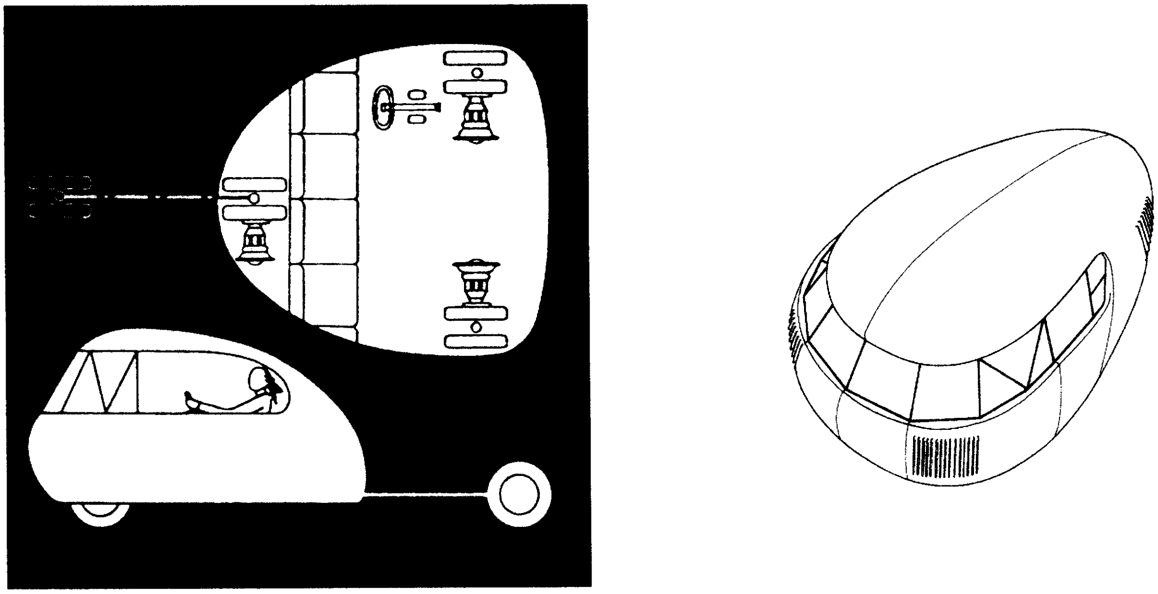


Fig. 4.27. (above)
BMW Isetta, 1955

Fig. 4.28. (below)
Smart ForTwo, 1999

the rear wheel when parking. Additionally, a telescoping boom moved the rear wheel outside the body for stability at higher speeds.

The Isetta (manufactured by Iso in Italy and later by BMW in Germany as well as other companies throughout the world) is one of the most recognizable small cars in automotive history. It was developed after World War II, when efficiency was a requirement and was intended as a car for the masses.
It measured only 2.30m in length, and challenged the conventional approach to car design of three boxes with a radical egg-like shape in a two-seater configuration featuring a single door opening at the front. This meant that the motorcycle engine used to power the car needed to be located elsewhere.

In 1994, Swiss watch maker Swatch collaborated with Mercedes Benz to create a car small enough that two of them would fit in one regular parking space. The car was named SMART (from Swatch Mercedes ART) and was 2.50m in length. The vehicle was very careful in its dimensions, so its efficiency for most types of travel is higher. Weight, for example is roughly 1,500 lbs, so it requires less energy to move one or two passengers than a conventional sedan.
It was launched in 1998 and while commercial success did not follow as planned, it quickly achieved an iconic presence in cities across Europe nonetheless. The Smart car, renamed ForTwo, still uses an internal combustion engine while electric and hybrid versions are being studied.

Notes

[1] U.S. Patent and Trademark Office. Patent #1631269

[2] United Nations Population Fund. http://www.unfpa.org/pds/urbanization.htm

[3] U.S. Census Bureau. http://www.census.gov/population/censusdata/urpop0090.txt

[4] United Nations Development Programme. http://hdrstats.undp.org/indicators/42.html

[5] National Household Travel Survey. http://www.bts.gov/programs/national_household_travel_survey/daily_travel.html

[6] JD Powers and Associates. http://www.jdpower.com/corporate/news/releases/pressrelease.aspx?ID=2008196

[7] U.S. Census Bureau. National Personal Transportation Survey. Statistical Abstract of the United States; 2000.

[8] U.S. Census Bureau. National Personal Transportation Survey. Statistical Abstract of the United States; 2000.

[9] Scottish Government. Scottish Household Survey Travel Dairy results. http://www.scotland.gov.uk/Topics/Statistics/Browse/Transport-Travel/TrendCarOccupancy

thinking outside the (three) boxes

the concept car workshop

The methodology of this research project uses the 'studio' or 'workshop' setting as the main environment for development. These settings are common among architecture and art schools and encourage participants to learn by doing, rather than by developing extensive research beforehand and speculating on the findings.

In 2003, Professor William J. Mitchell stepped down as Dean of the School of Architecture and Planning at MIT to become Head of the Academic program in Media Arts and Sciences at the MIT Media Lab, where he also set up the Smart Cities research group. The goal of the Smart Cities group was to explore intelligent designs for sustainable buildings, mobility systems and cities. Its agenda was very broad, but gravitated around the application of new technologies in the design of urban life.
Professor Mitchell gathered a multidisciplinary team of students and researchers from MIT to work on the first formal project of the Smart Cities group, called the "Concept Car Workshop". Registered students were eligible to apply to limited number of seats in the workshop. The team did not have a specific design in mind. The

Fig. 4.1
Concept Car workshop meeting

agenda was open and students were encouraged to abandon any preconceived ideas about cars, re-think the car as a design object and explore the relationship between people, cars and cities. The team of people that participated in the workshops came from backgrounds as diverse as urbanism, architecture, industrial design, mechanical and electronic engineers, as well as software programmers. The workshop offered a blue sky to study any kind of ideas related to the future of transportation, far from the constraints of the automotive industry.

The workshop also included the participation of executives from General Motors, a long-time collaborator of the institute and a sponsor of the MIT Media Laboratory. Over the years, the level of collaboration with the Smart Cities projects has varied, but the interaction with the group has been fluid, mostly limited to participation as guest critics in different reviews. A number of different executives have visited the group, but former head of design Wayne Cherry, Larry Burns and Chris Borroni-Bird have had the most interaction with the group.

In the beginning, Professor Mitchell's idea was include the participation of renowned architect Frank O. Gerhy, but this collaboration never fully materialized. Gehry himself, James Glymph and other members of the firm participated in a few occasions as guest critics of the work produced by the group, without getting involved in the actual production of any designs.

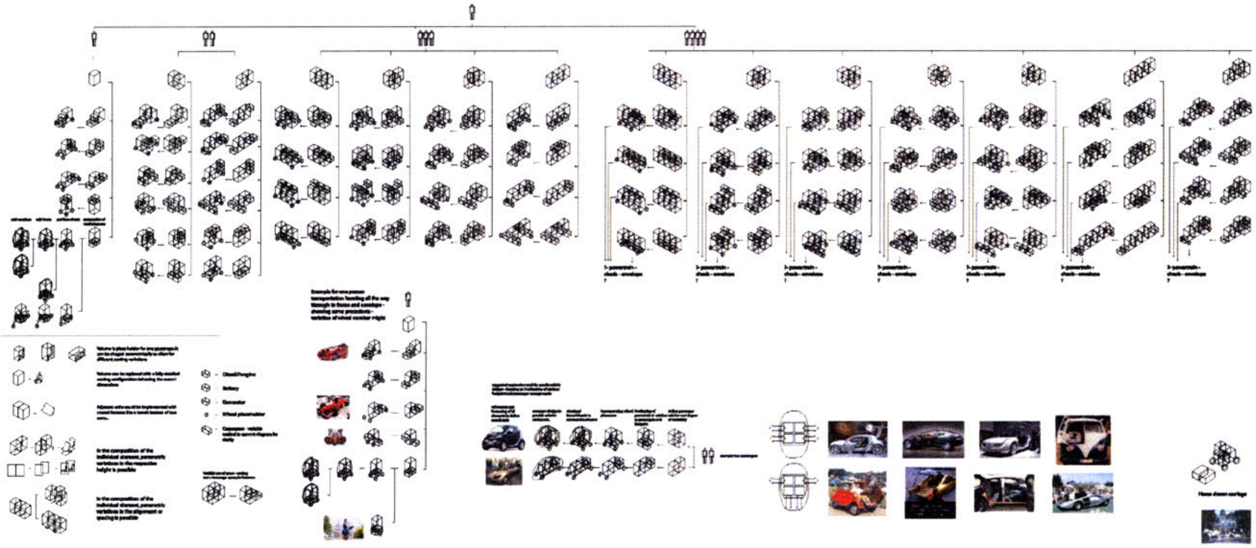
As explained later in the next chapter, a small team within the Smart Cities group quickly focused their research in the major challenges of urban transportation. Traditionally, urban designers attempt to tackle transportation problems in a city with interventions on the urban fabric that range from surgical. In other words, it is the city who has to constantly adapt to meet the demands of cars. The goal with the concept car workshop was to reverse this approach and have urban planners and architects create car designs that would reflect the characteristics of urban life in the 21st century.

Although this is not an attempt to document the work carried out in the "Concept Car" workshop at the Media Lab, in order to understand the process that would lead to the development of the city car, it is important to highlight a few notable contributions to the group.

Solution space

One of the first ideas that influenced the entire group was Axel Kilian's solution space diagram. The work stripped down the basic components of a standard automobile into geometric primitives and charted all possible combinations of these elements in a tree diagram. The graphic became a reference for the group to mark down existing car configurations, and at the same time, indicating new directions to explore. This is a very interesting method of computing operations and yields a large

Fig. 4.2
Solution space diagram by Axel Kilian



number of results in what is considered the solution space. One of the main obstacles when computing with a given set of elements (or units) is that the number of possible solutions is also predetermined. Professor Stiny highlights that creativity is not only in recombining these elements, but most importantly, in the emergence of new units that can trigger an infinite number of possibilities.

Let us imagine, for example, a given number of elements that may constitute what we understand for a car. A block is the passenger cabin, another block is the storage unit, another block the drive-train, and finally three or four smaller units as the wheels. In Kilian's diagram, the passenger space is individually formed; that is, each passenger claims its own block. After a few iterations, one can easily understand different configurations and find new ones.

Robot wheel

The shortcoming of this approach was demonstrated by the work under exploration by Patrik Künzler. As mentioned before, the workshop was open to investigate any kind of ideas, not necessarily connected to each other, and in most cases, the work was driven by personal interests. Künzler was interested in finding ways of reducing what is called "unsprung mass" in a vehicle. Unsprung mass constitutes any weight that is not connected the suspension elements of a car. The mass of the body and other components supported by the suspension is the sprung mass. His research quickly evolved into a complete redesign of an automobile wheel, with an embedded suspension system.

Shortly after that, Künzler created what would be one of the most influential contribution to the group by packaging

Fig. 4.3
Robot wheel by Patrik Künzler

all the components necessary to propel a vehicle in the space of a wheel. This became known within the group as the "robot wheel". Robot wheels are in essence a new element born from the combination of the drive train and the wheels. Each of these wheels could hypothetically work independently from each other or in a synchronized manner, through the use of electronics. At first, this might seem nothing more than an interesting concept but it had profound implications in most of the designs carried out in the workshop, including the city car. Robot wheels eliminate entirely the space requirements of a traditional drivetrain (engine, transmissions, driveshafts, differentials, etc).
While much of the attention was focusing on a combinatorial approach of the elements dictated in the chart of the solution space, it could not have anticipated Künzler's contribution, because it virtually eliminated the spatial requirements of a standard engine.

Athlete car

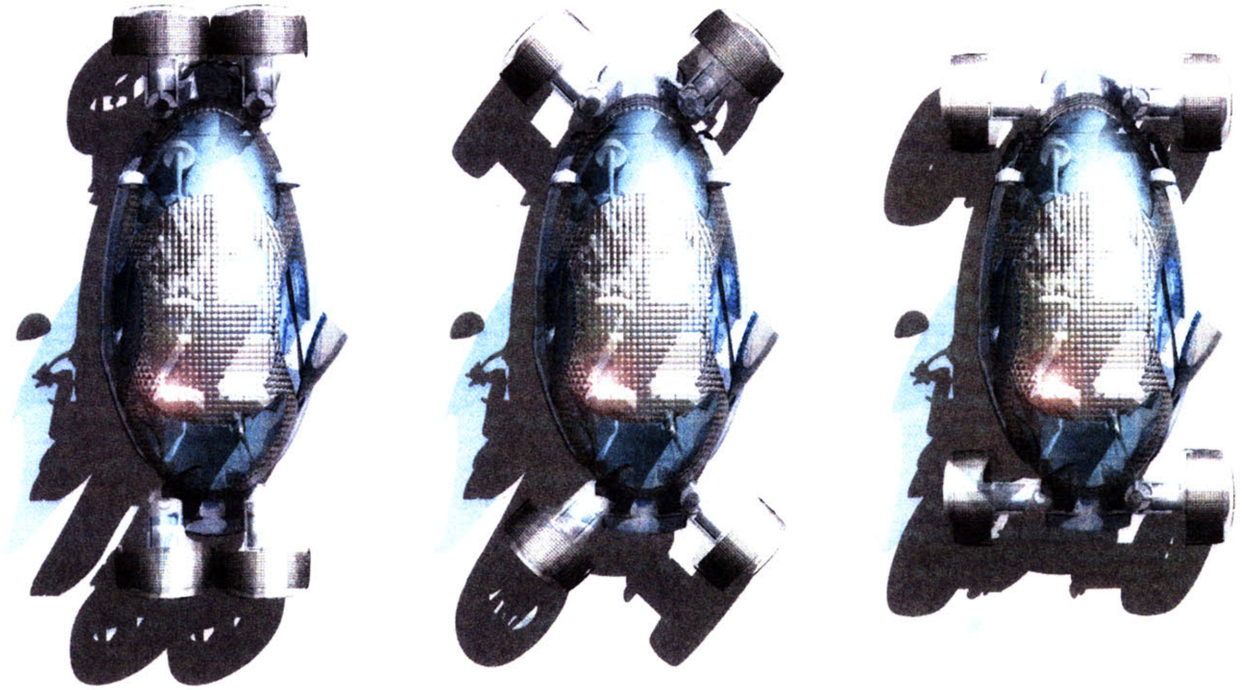
Fig. 4.4
Athlete Car

The group explored different concepts in parallel. Another concept worth noting was the so called "Athlete Car", also conceived and largely developed by Axel Kilian. The idea behind the "athlete car" was a different kind of performance vehicle, one based on the motion of the human body, following the choreography dictated in certain activities or sports, such as skiing, ice skating or even ballroom dancing. Kilian, Joachim and a number of other students, designed several variations of the "athlete car". The main concept was based on an dual frame articulated in the middle. The passenger cabin would be defined by a flexible skin, capable of stretching and contracting, adapting to the forces exerted by the motion of the car.

Soft Car

Mitchell Joachim's work was another pivotal contribution to the group, both in terms of quantity and quality. Joachim produced a substantial number of concepts that would be impossible to enumerate here, which are documented in large part in his PhD dissertation on Ecotransology. Nevertheless, it is necessary to mention a few of his ideas here in order to understand the evolution of this research.
The group in the Concept car workshop began to study different aspects of urban mobility, and one of the first themes was circulation patterns in the city. That is when Joachim presented to the group his idea of a soft-skinned vehicle. Much like animals, that softly bump into each other and things without causing damage, these cars with some kind of flexible skin would eliminate the driver's obsession of maintaining a pristine metallic surface. When they rub

Fig. 4.5
Soft car by Mitchell Joachim



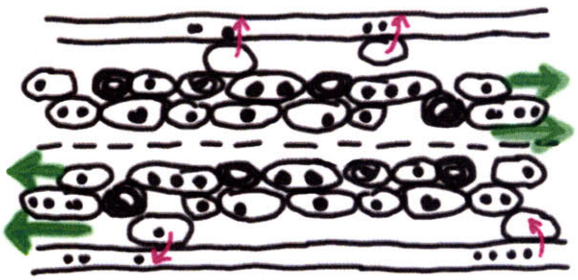


Fig. 4.6
Gentle congestion by Mitchell Joachim

up against each other, they do not scratch or dent and fatal accidents less likely to happen. This allows denser packing and gentler negotiation of routes in traffic streams and parking lots. The Soft car led to the concept of "gentle congestion", which describes a pattern of movement similar to a flock of sheep. [1]
Although these ideas would eventually affect to a different degree the conceptualization and evolution of the city car, the first clear and undeniable precedent is a particular element in Joachim's soft car. He first introduced to the group the notion of perpendicular parking by sideways translation. This concept is not a revolutionary new idea, but the Soft car was the first design within the Concept Car workshop to incorporate this feature. Although the idea was well received in the group, it did not resonate with other team members until much later.

Five points of future car design

Emulating LeCorbusier's famous "five points of architecture", Professor Mitchell created a new list of design principles for the car of the future, largely based on the results produced by the team up to that day. These five points were:

1. Motor-Wheel
Electrically powered, independently controllable wheels with motor, suspension, brakes, and steering contained within each wheel assembly. Placing the suspension within the wheel itself is a significant innovation, and promises some important advantages. Each wheel has only two inputs: electrical power and digital data.
Goal: Create self-contained mobile units

2. Exoskeleton
An exoskeleton that connects the wheels

and supports the passenger cabin, storage units, and power source. This element can be optimized for structural efficiency, and (like the frame of a sophisticated bicycle) can become a major design feature.
Goal: High level of customization

3. Drive-by-Wire
In place of traditional steering column and dashboard arrangements. This allows radical reconfiguration of the cockpit, treatment of the passenger compartment as a module that can readily be separated from the rest of the car, and creation of a multimedia driving experience that intelligently integrates data streams from a wide variety of sources and presents them to the driver and passengers in a customized, context-sensitive way.
Goal: Interior Design Freedom

4. No Crumple
A lightweight, technologically advanced passenger compartment suspended safely within the exoskeleton, like an egg protected within an egg carton. This compartment need not be fabricated from sheetmetal and glass. It can exploit the possibilities of advanced materials and embedded electronics to provide high levels of visibility, safety, climate control, lighting, sensing capability, and interior displays. And it provides an opportunity to break away from the familiar automobile aesthetic of painted sheet metal

5. Hold Safely
Go beyond seatbelts and airbags. Think of the passenger seat, from the beginning, as a gentle robot that knows how to hold you safely and comfortably under any conditions that may be encountered.
Goal: zero passenger deaths.

For organizational purposes, the following chapter describes the departure point that would lead to the design of the stackable city car, but it must be mentioned that the design process was not always linear and clear. Many of the concepts were developed in parallel and influenced each other, sometimes they were abandoned for a while and then resumed at a later time.

The concept for a stackable, shareable car for urban trips was developed over a period of incubation until a convincing design was presented and discussed in the group. Eventually, Professor Mitchell decided to focus the attention of all team members of the Concept car workshop into the development of the project that became known as the City Car.

Notes

[1] Joachim Mitchell, Kilian Axel, Mitchell William; Transology: Reinventing The Wheel. http://www.archinode.com/Joachim_Transology.pdf

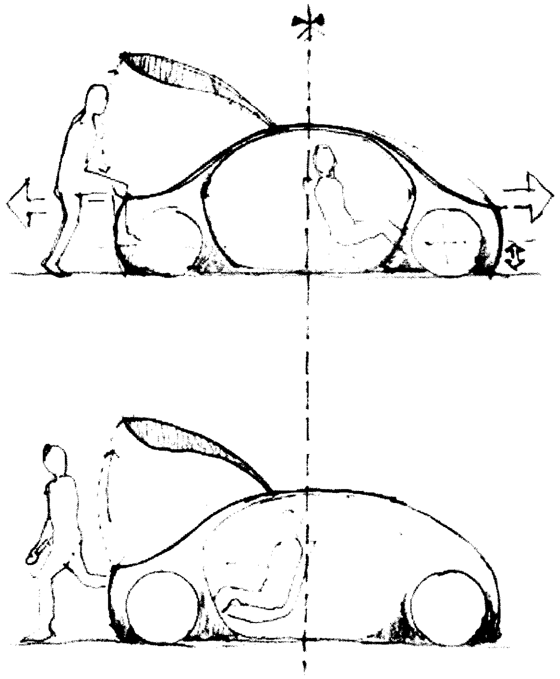
omnidesign

city capsule and city rover

When the Concept Car workshop was initially set up, the rumors about renowned designer Frank O. Gerhy's involvement in the project quickly propagated in the design world. Naturally, almost everyone who heard the news was able to immediately predict the outcome of such a collaboration: Gehry would design a wacky geometry with curved planes and no symmetry, while the MIT engineers would find the best technological implementation to make it run.

For good or for bad, this assumption could not be any further from the reality of the workshop. In the workshop, roles quickly disappeared and Gehry's collaboration with the students never materialized beyond one or two reviews.

Fig. 5.1
City capsule sketch



City Capsule

Almost to rebel against what was expected from the group, one of my first designs deliberately used symmetry as a functional premise. The diagrams illustrate a concept for a vehicle with a single-volume body, with symmetry applied on two planes. This eliminates the notion of front and rear. Either end could become the front, depending on the

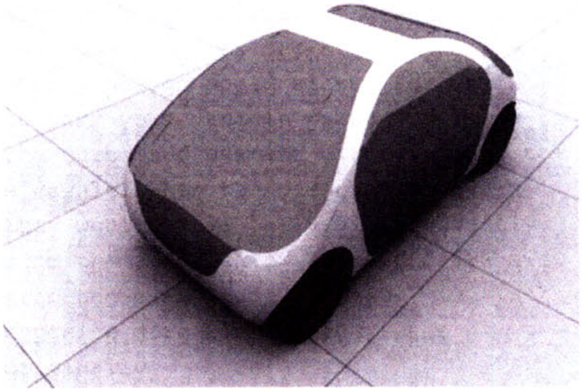


Fig. 5.2
City capsule

position of the driver and the car would drive indistinctly in both directions. Although not strictly necessary, the car also featured ingress/egress points at the long ends, as opposed to the sides. Such a design would allow, for example, to park your vehicle perpendicularly to the curb, and descend directly onto the sidewalk. When the passengers return, they would enter the vehicle directly from the sidewalk again, and drive away from the exact same position, but in the opposite direction as they came originally.

This concept requires careful consideration of the interior space as well because it needs to be designed for maximum flexibility of use, since at least the driver's seat and controls must be able flip, rotate or be reconfigured to face opposite directions. With hatch doors opening on the front long ends, getting out of the vehicle is significantly easier because the driver just stands up and walks out of the vehicle. Ingress to the vehicle, however, presents a number of challenges. If the seat and the person are facing each other [scheme 1], the person will need to rotate before sitting. Once seated, the seat will need to rotate 90 degrees and put the driver facing the new direction of the car. Alternatively, if the seat is facing

Fig 5.3 (opposite page, top)
City Rover sketches

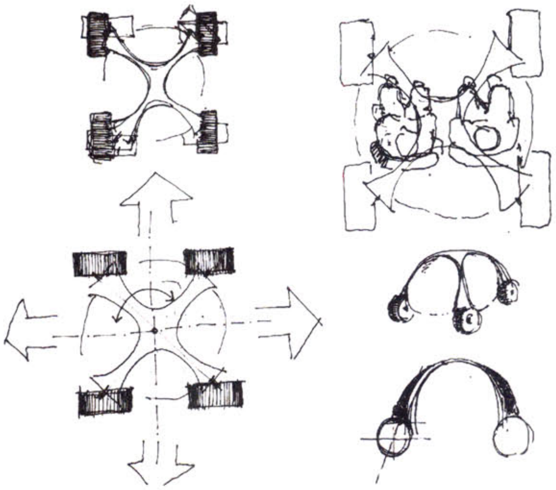
Fig 5.4 (opposite page, bottom)
City Rover

away and already aligned with the new driving direction [scheme 2], it gets increasingly difficult for the person to reach inside the constrained space of the vehicle and sit on it.

City Rover

In early 2004, Patrik Künzler, William Lark Jr. and myself teamed up during a brainstorming session to generate new designs in the Concept Car workshop. I was still intrigued by the idea of symmetry I had just explored in the City Capsule concept but wanted to take a step further in its function. The result of this brainstorming session is the original sketch presented in figure 88.

The City Rover is a small spherical capsule for two passengers designed for driving in four directions. This was the first design to incorporate and explore the potential of the robot wheels. The spherical cabin was connected to four robot wheels capable of rotating 90 degrees (plus, minus 30 degrees for additional steering) and moving the car in any direction.



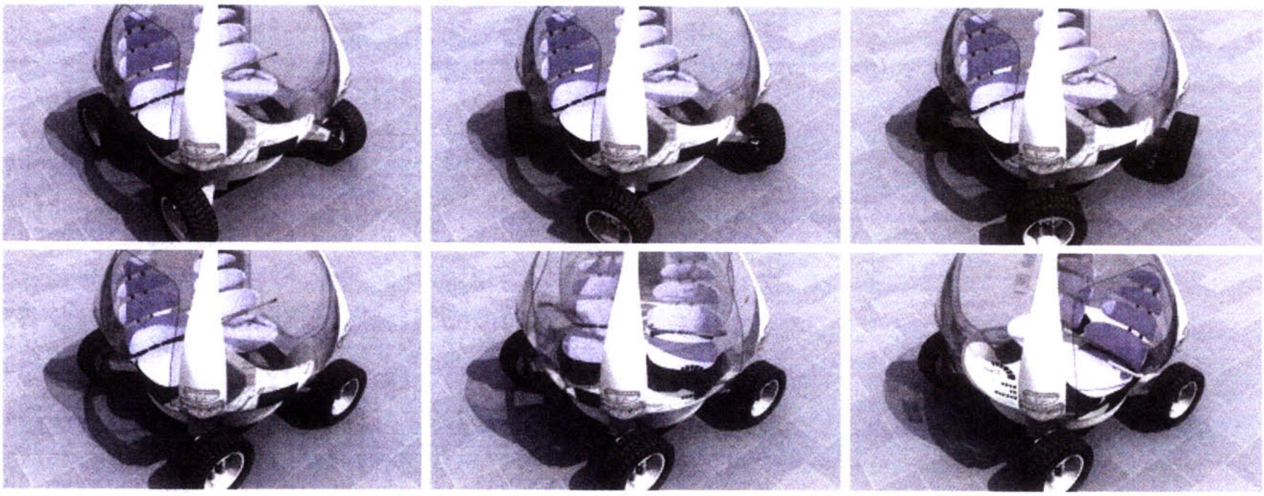
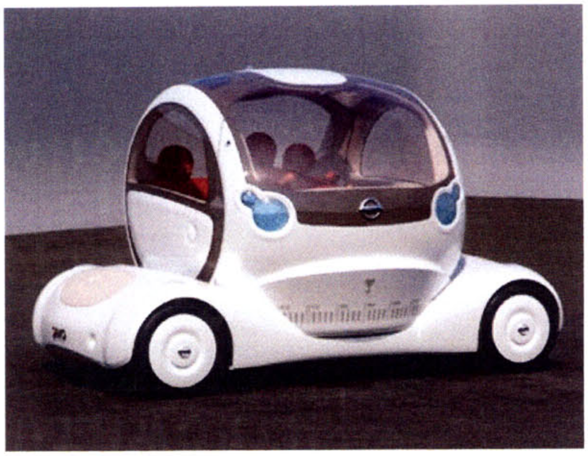


Fig 5.5
City Rover turning sequence

It was evident that driving your vehicle sideways could prove extremely useful in certain situations, but since the field of vision of the driver was still facing another direction, we decided to add one more twist, by creating an intermediate structure. Thus, the wheels would not be attached directly to the passenger cabin, but to a supporting frame. The cabin, in turn, would also be attached to this structure with a major articulation in the center, so that it would be able to rotate in intervals of 90 degrees at a time, and allow for the driver to always face the direction of movement.
In practical terms this design is a fully omnidirectional vehicle, in which the front and rear are only determined by the direction faced by the passengers. The success of this design is in the combination of four independent wheels that are not connected to an axle and capable of rotating on its own vertical axis, with an articulated rotating passenger cabin. This design caught the attention of the group, visitors as well as the media. In XXX 2004, the vehicle was published over a two-page spread in Intersection magazine (UK) alongside an article named "The shape of cars to come" describing the work in the concept car workshop.

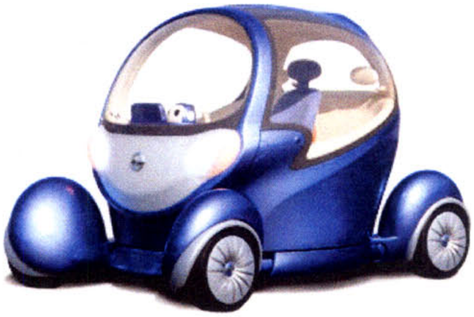
Fig 5.6 (right)
Nissan Pivo, 2005

Fig 5.7 (below)
Nissan Pivo 2, 2007



Nissan Pivo

The MIT Media Lab always received visitors from all backgrounds and the work of the Smart Cities group was frequently on display for everyone to see. In contrast to the secretive world of the auto industry, the academic spirit is always open to the exchange of ideas because that is primarily how innovation happens and progress is made. Additionally, the Smart Cities group received guest lecturers and critics from some of car manufacturing companies on a regular basis, including Renault, Ford, Ferrari, and many others.
About 18 months after the City Rover was designed and presented in the group, Nissan Motor Co. unveiled in the Tokyo Motor Show a remarkably similar concept, called Pivo.
The Pivo featured a rotating passenger cabin attached to a fixed rectangular base. Unlike the City Rover, however, the wheels were fixed in one direction, so the purpose of the rotary cabin was not entirely clear.



In 2007, Nissan introduced the second version of the Pivo, aptly called Pivo 2. This new version was even more similar, if not in the quir exterior appearance, at least in the overall concept.

Each of the four wheels are powered by advanced electric hub motors, which can then swivel 90 degrees allowing the Pivo 2 to drive sideways as well as forward. The only difference with the City Rover concept was that the intermediate structure connecting the wheels to the cabin is underneath cabin rather than on top of it, which probably makes most sense structurally and does not create conflict with the field of vision of the driver.

folding and stacking

a car for parking

The agenda of the Concept car workshop was still very open, and there were several directions being studied in parallel, but after a short presentation at the Media Laboratory given by Prof. Ralph Gakenhiemer, we became more focused on the relationship between the automobile and the city. Besides circulation patterns, which was still being studied in the group, the other aspect we decided to tackle was the problem of parking.

Fig 6.1
Luggage carts at the airport

I teamed up with William Lark Jr. again with the objective of creating a different kind of car. Most cars are designed for driving; our car, instead would be designed for parking. The exercise was meant to explore possible solutions for parking arrangements and deliberately ignored other constraints. The vehicle needed to be capable of carrying at least one person and reduce as much as possible the space requirements when not in use. The obvious references came from space-saving structures found in everyday objects, more specifically from collapsible and stackable designs. These structures have some kind of adaptation that transforms their volumetric needs either as a single object or in a group. For example, a single chair may take an approximate volume of XX ft3, but when stacked with 10 other units the total arrangement is XX ft3, or XX ft3 per chair. While not common in architecture, these designs are ubiquitous among industrialized products, from plastic cups, to furniture, to luggage carts at the airport.

The first iteration consisted of an open structure for a single occupant. The concept was illustrated in a series of images and animations and discussed within the group.
The vehicle itself was nothing more than a frame mounted on four wheels, which tapers towards the back, so that another identical structure would fit inside its empty space. To enter the unit, the frame lifts up a hatch door in the front giving direct access to the driver's seat. In order to overlap as much as possible of the footprint of the vehicle with another car, the seat folds up together with the frame of the hatch door.

This design did not resolve the method of propulsion but it reserved the rear portion of the car behind the driver's seat for a small engine, a battery pack or other components of the drivetrain. In contrast to the actual cabin space, which is mostly empty space when the car is not occupied, these mechanical components are very compact and typically, they cannot be collapsed into smaller structures. Therefore, the dimensions reserved for these components would determine the maximum efficiency of the stackable structure. Although this vehicle was not developed any further, arranging the necessary mechanical components for moving the car and providing it with an enclosed passenger space seem feasible. Still, collapsing the passenger cabin in such a way so that its empty space could be taken by other units when overlapping, presented a number of challenge. The

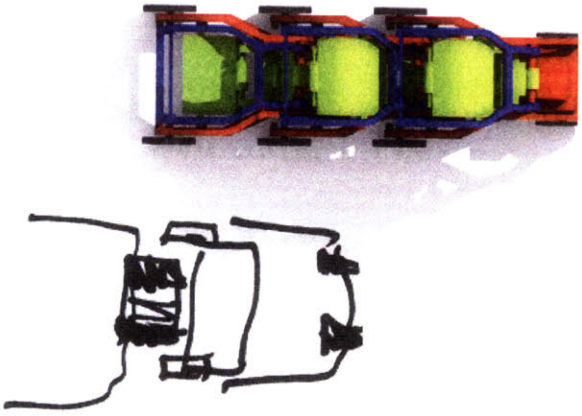


Fig 6.2
Plan view and sketch of original collapsible car by Franco Vairani and Will Lark Jr.

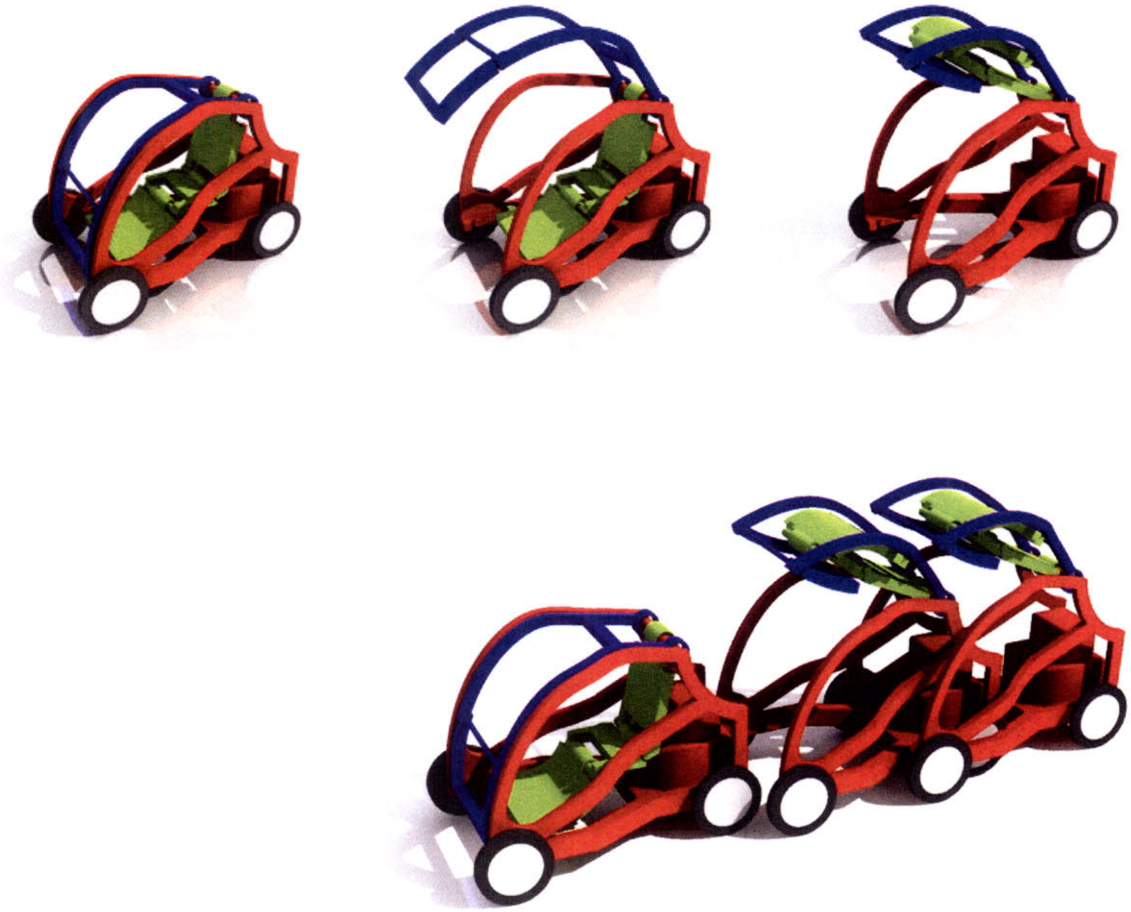


Fig 6.3 (above)
Folding and stacking sequence for a collapsible car by Franco Vairani and Will Lark Jr.

Fig 6.4 (below)
Portable folding laptop by Dell

interior elements need to be protected when the structure is open for parking and the cabin space must be properly insulated from the elements when driving.

The idea, however, was extremely provocative and was well received inside the group. It was clear that there was potential in it and further investigation was needed.

Collapsible design

Although the idea of a stackable a car might appear unusual at first, collapsible designs are extremely common in every day objects. Collapsibles are man-made objects that accommodate to

change. They can be grouped into three broad categories according to the main purpose of their collapsible feature: for economy of space and/or transportation, for additional functionality (besides that of more convenient storage and transportation), and/or for protection of certain components.
Objects that are candidates for collapsible design often present three characteristics: they have impractical shapes and dimensions, they usually take up a considerable amount of "empty" space when in use (although this "empty" space is necessary for them to function), and they are not in use all the time. Therefore, it makes sense (and sometimes it is mandatory) to optimize the shape of these objects in order to utilize this empty space for some other purpose when the object is not in use. Collapsibility is always a means to an end: there must be an advantage in reducing the size or transforming the overall shape of the object, or else there is no value in it. Besides, they usually require an additional level of complexity that needs to be justified later on.

Fig 6.5 (above)
Sliding cellular phone by Sony Ericsson

Collapsible designs re-distribute the impractical volume occupied by the object in some other way. Naturally, unless the object is physically compressed, the volume of the artifact itself does not change, it is just re-distributed so that it takes up less useful space or provides additional functionality to the product. (Mollerup 2001)

When an object is designed to be collapsible, it features at least two distinctive states. In the case of collapsible for economy of space, they correspond to an "active" mode and a "passive" mode, depending on whether the objet is in use or not. These two states are complementary of each other. If the

Fig 6.6 (below)
Retractable landing gear in a commercial airplane

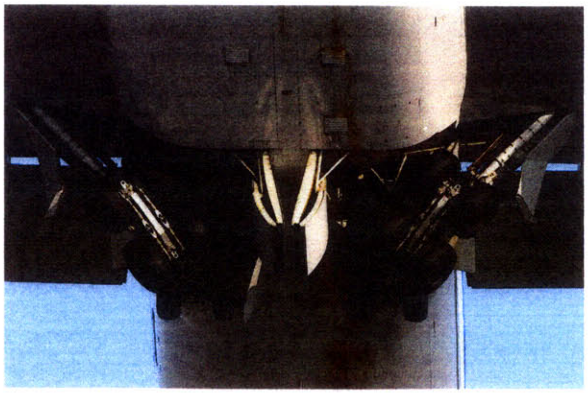


Fig 6.7 and Fig 6.8 (above)
F/A 18 fighter jets with folded wings aboard the aircraft carrier USS Dwight D. Eisenhower

artifact can perform all its functions in its collapsed mode, it probably has no purpose to exist in a fully expanded fashion, and the design is simply redundant or just a gimmick. The function of the active state is that of the primary purpose of the object. The second state will accomplish an additional function, or fulfill the requirement of convenient storage or transportation. For example, a flip cellular phone is unfolded and activated to receive an incoming call, but when the user hangs up, it is folded in half so that it fits comfortably inside his/her pocket. Still, in the "passive" mode, the phone will be capable of notifying the user of an incoming call and maybe display the caller's information. Other collapsible designs will only operate in its active state.

There are many categories of collapsibles, which can be organized based on the mechanics of the transformation:

- folding
- sliding

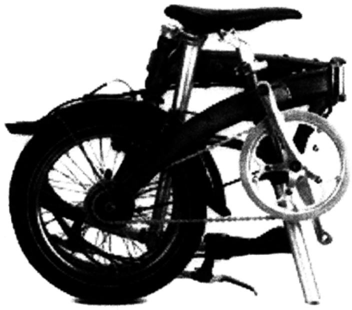
- assembling
- nesting
- inflation

However, collapsible objects often employ a combination of these principles to create more efficient designs. It is not uncommon to find an assembly with a sliding mechanism, such as camera tripod. And it is also possible to find a finer grain in each of these categories. For example, it is possible to fold an object thanks to a crease in its surface or by rotating a part around a hinge, which present different considerations at the time of creation.

The idea of better utilizing the space taken up by transportation devices while they are not being used is hardly original. In situations were real estate is at a premium, collapsible design may be an absolute necessity, and there are examples from small portable objects to large scale implementations. One of this clear examples is an aircraft carrier at sea. Highly complex machinery such as military helicopters and fighter jets must incorporate mechanisms to reduce their footprint to a minimum on the deck of the carrier, even at the cost of additional millions of dollars.

Another closely related precedent are folding bikes. For years, there have been designs that sought to reduce the space taken up by a bike in very creative ways. During World War II, British soldiers already carried collapsible bicycles and motorcycles. Since 1982, Dahon, Inc. is one of many companies that manufactures and sells folding bicycles in the United States. Their motivation was to offer a product that would integrate efficiently some means of personal mobility for commuters with mass transit systems, and since a regular bike is too awkwardly big to carry inside a train or a bus, these bikes can fold to less than a half of

Fig 6.9
Dahon foldable bicycle



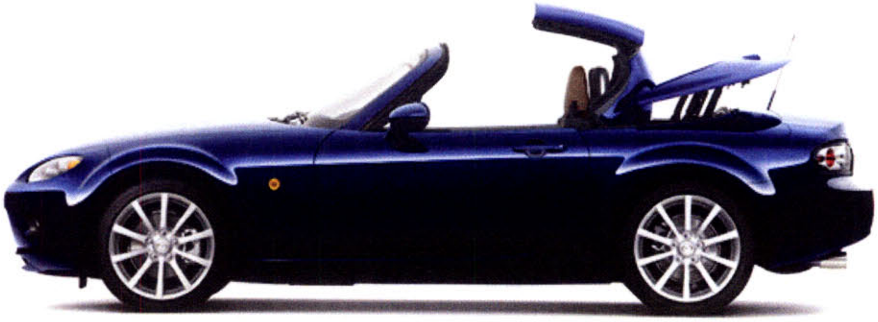


Fig 6.10 (above)
Mazda Miata MX-5 with power retractable hardtop

their original size.

Retractable rooftops were already common in carriages, so they made a natural transition into automobile design as well. There are countless examples of early cars with folding roof, most of them as soft tops, but also some notable retractable hardtops, such as that of the Peugeot 601, back in 1934. In these cases, the main goal of the folding mechanism is not to save space, but to provide additional functionality to one single product. The car allows the driver and passengers to enjoy the good weather while driving but is also capable of offering protection when the conditions are not favorable.

In the realm of automotive design, especially for a group of novices such as the team members of the Smart Cities group, it seemed that everything had been tried before. But most of the times, we could not use them as precedents because we learned about an existing concept after we had cracked our heads imagining how it would work. The idea of reducing its volume or its footprint while the car is not being used seemed unorthodox at first, but soon enough we discovered we were hardly the first ones to attempt it.
In 1929, German engineer Engelbert Zaschka, known for his design of a

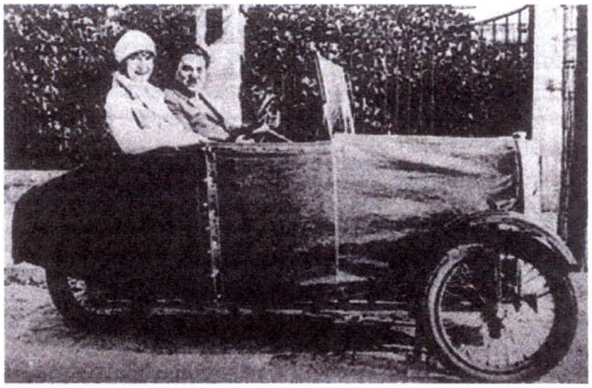


Fig 6.11
Three-wheel collapsible car by Engelbert Zaschka

human-powered aircraft and his unusual helicopters, also designed a three-wheeled folding vehicle. This car could be assembled at home or put aside in a suitcase when not in use.

Renault Zoom

The idea of folding a car in half and thus reducing its wheelbase to economize on parking space is also not exactly new. In 1992 at the Paris Motor Show, Renault presented a concept named Zoom. The small 2-passenger vehicle was a single volume with a total length of 265 cm when driving. It was equipped with an electric motor and a pivoting mechanism that allowed for the rear axle to move forward, while lifting the body of the

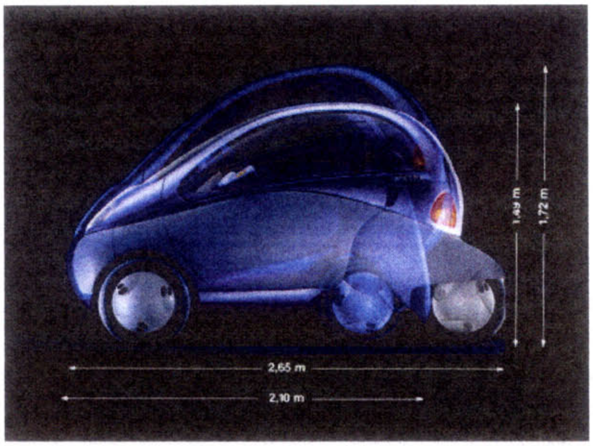


Fig 6.12
Renault Zoom concept, 1992

car by 23 cm. This would reduce the overall length of the car by 55 cm which allowed the car to park in much tighter spaces than regular cars. Additionally, the car featured scissor doors (also known as beetle-wing) that rotate upward on a hinge near the windshield to reduce the required lateral clearance when parked. The concept car never went into production.

Taxi2work

It was not until much later, when the first images of the city car were widely published on the Internet and reproduced on countless blogs that similar designs came out in the light.
In January 2005, roughly six months after the first version of the bit car was created and presented in the Smart Cities group, the website engadget.com received a response from the reader pointing to a design patented in 1995 by Richard Shultz.
Shultz's design featured an rough concept of vehicles that would fold and interlock into one another to reduce the required footprint. The drawings in the patent lack dimensions and details, but the overall concept is somewhat understandable.

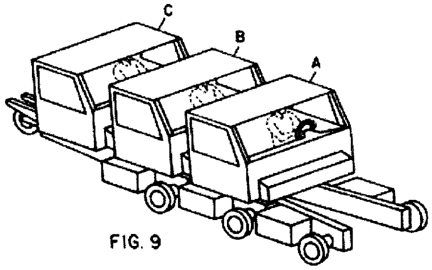


FIG. 9

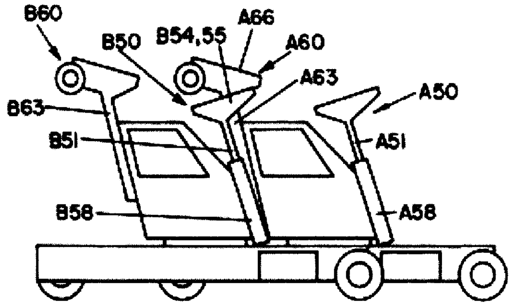


FIG.6

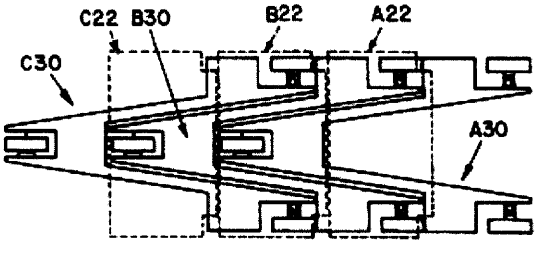


FIG.7

Fig 6.13
Taxi2Work diagrams by Richard Shultz

Toyota PM

Fig 6.14
Driving modes for Toyota PM concept

In 2001, Toyota introduced the first version of the personal mobility system, known as Toyota PM. In the following years, a number of different vehicles have been added to the line-up, focusing on small, light-weight devices for individual transportation.

The first vehicle presented, simply known as Toyota PM employed a sliding mechanism to move the car into an upright position. In this case, the rear wheels slided on a fixed rail on the bottom of the cabin's body which pushed the cabin vertically. The purpose of

Fig 6.15
Toyota PM concept

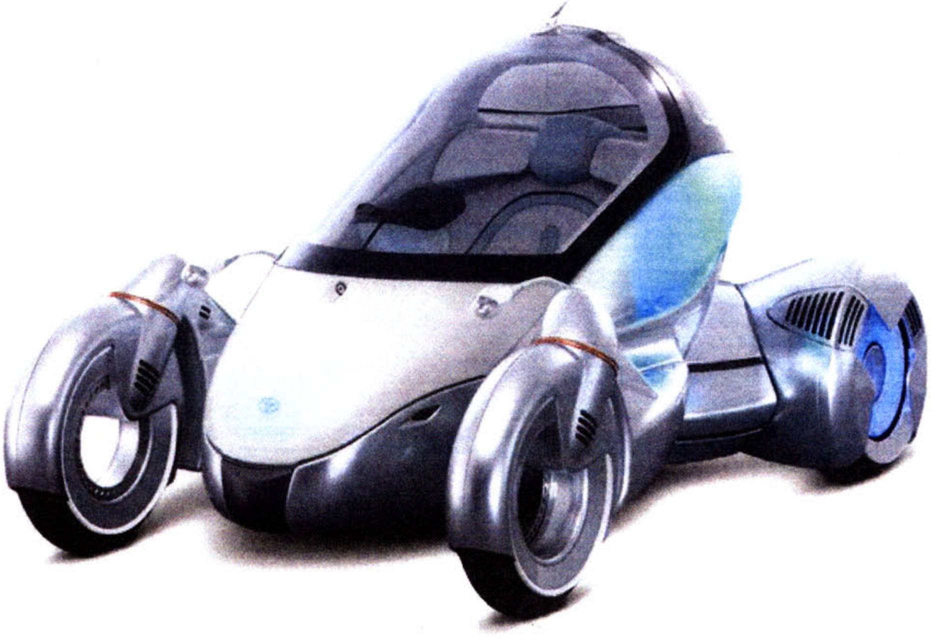


Fig 6.16
Toyota PM concept

this design was to offered different functionality and a variety of driving modes: the car is almost horizontal for driving at higher speeds, in an intermediate position for slower and more precise manoeuvring in congested settings and almost vertical for ingress and egress. Unlike the Zoom concept by Renault, which specifically sought to reduce its parking footprint, the Toyota PM does not make any direct references to its relationship with the context, although it would be safe to deduce the gains in terms of parking space when the car is upright position.

crumple zone
form and function in a collapsible car

The first proposal for a vehicle with a high parking efficiency was nothing more than a collapsible frame with a seat, not too different in spirit from an actual shopping cart. While a unit like this could indeed provide adequate personal mobility in certain cases, it does not offer the same qualities for passenger travel as an automobile. The challenge became to design a vehicle applying a similar principle for collapsibility and at the same time provide it with an adequate level of quality, comfort and protection for the riders.

As discussed before, the design of a passenger cabin in a traditional automobile is mostly determined by ergonomics: the shape of the space corresponds to a general scheme of four seated persons, two in the front, two in the back. The previous exercise demonstrated that the passenger space contained a large amount of empty space that could be re-distributed when the car was not in use. Baby strollers use this principle extensively. They can greatly diminish the required space thanks to a folding frame that allows for a virtual elimination of the "passenger space". However, this also presents a major obstacle not easy to overcome. When a structure is designed

to be collapsed, there are joints and movable parts which, in turn, present a challenge for insulation. This is not a problem for the stroller, because the unit is open and offers minimal protection against the elements (if any). Collapsibility in a baby stroller is further enhanced by the use of fabrics, which have no internal structure and can adopt many different shapes. But in contrast to strollers, it is expected that cars provide excellent weather protection and safety for its occupants, so the use of fabrics as the main component for the cabin is usually not practical in most climates. Therefore, applying the principles of collapsible design to automobiles requires additional considerations because rigid elements need to be carefully partitioned and arranged into a stable kinetic structure. This is not impossible to achieve, of course. A standard car door is a movable piece of the cabin that is equipped with proper insulation and waterproof joints. But these joints increase the complexity of the unit, its manufacturing cost and the chances for problems, so designers try to avoid them as much as possible.
For these reasons, it was decided to keep the passenger cabin as a single, non-collapsible unit, and look for opportunities to save space elsewhere. In reality, the folding frame used in the first exercise is a secondary requirement of the collapsible structure. In other words, when the structure has completely folded, there is still no gain in space. The gains are present when one unit is stacked into another, that is, when there is an effective overlap, and the standard space of one car is shared by two or more units.

As discussed in chapter 3, the different layouts for car parking are more or less efficient, depending on a number of variables, but they are ultimately confined by the dimensions of the 'design vehicle'. In order to increase the actual density of a piece of land destined for parking, it is necessary to build structures that can accommodate vehicles in the third dimension. But this is an adaptation of the city fabric to the demands of the automobile. With the goal of the workshop in mind of adapting cars to cities rather than cities to cars, we thought the solution ought to be embedded in the vehicle instead.

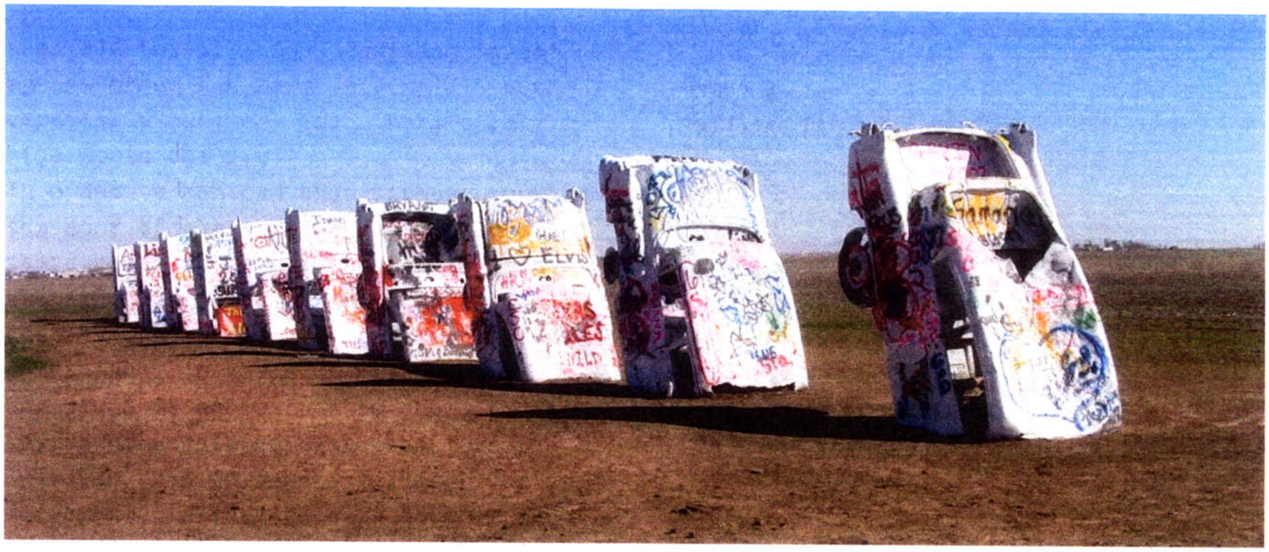
Cars and most other vehicles are typically horizontal structures. Arguably, books when they are open so that its pages can be read are also horizontal bodies, but nobody thinks of organizing a library so that all books are always open. Instead, they are placed vertically so that they take as little space as possible. However, we keep our unused cars in the most inefficient position possible, taking up valuable space from the city. Since the height of cars averages 1.50m and the

Fig 7.1 (above)
Standard vehicle arrangement

Fig 7.2 (below)
Alternative vehicle arrangement

length is around 4.50m, arranging cars vertically would be very efficient, but unlike books which can be easily handled, it would prove challenging to lift these heavy machines many times a day. But cars do not need to be fully vertical to save space. There are also intermediate positions that can still result in more efficient arrangements; what is necessary is to lift a vehicle enough so that another unit can squeeze underneath the first one.

The arrangement would look similar to



the 1974 installation "Cadillac Ranch" by the group Ant Farm, having all cars vertically aligned, with their trunks high up in the air.
In order to achieve that without burying the hood of the cars in the ground, there needs to be a mechanism to lift the front or the rear up, high enough so that another car would be able to fit underneath. In terms of design, the technique is equivalent to changing the layout of a parking plan from linear (parallel) to 45 degree parking. The difference is that this is done in the third dimension (the car is angled in the Z plane) so the space above the car

Fig 7.3
Cadillac Ranch by Ant Farm

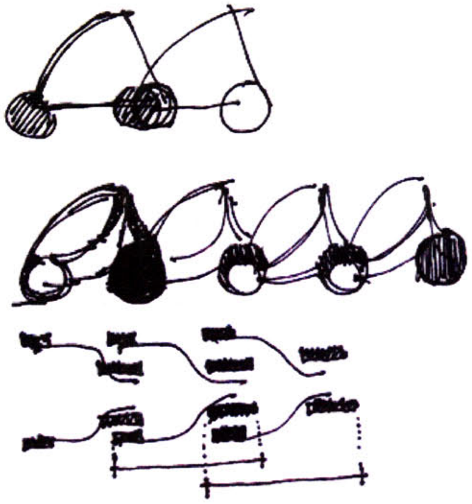


Fig 7.4
First sketches for a stackable vehicle

is utilized. Furthermore, if the car itself is equipped with this mechanism, then there is no need to build some kind of external infrastructure to achieve high density parking. This are two very important aspects because the scheme would work in most situations, as long as there is sufficient free space above to distribute the space of the car.
The most space-saving scheme (at least in plan) requires that cars be angled as much as it is necessary for another car to fit. The exact angle depends on the shape and dimensions of the cars to be stacked, but it could range from a few degrees to almost perpendicular to the ground plane.

If you are going to lift anything, ideally, the load should be as light as possible. The design of the robot wheels is a perfect complement for this purpose, since the car has no longer a heavy engine, and all the mechanical parts are instead located inside the wheels themselves, which always remain on the ground. At the same time, a traditional three-volume body gets in conflict with the pivoting mechanism, as the front engine box could hit the ground when the car is rotated and moved upward. So the design of a collapsible vehicle greatly benefits from the use of

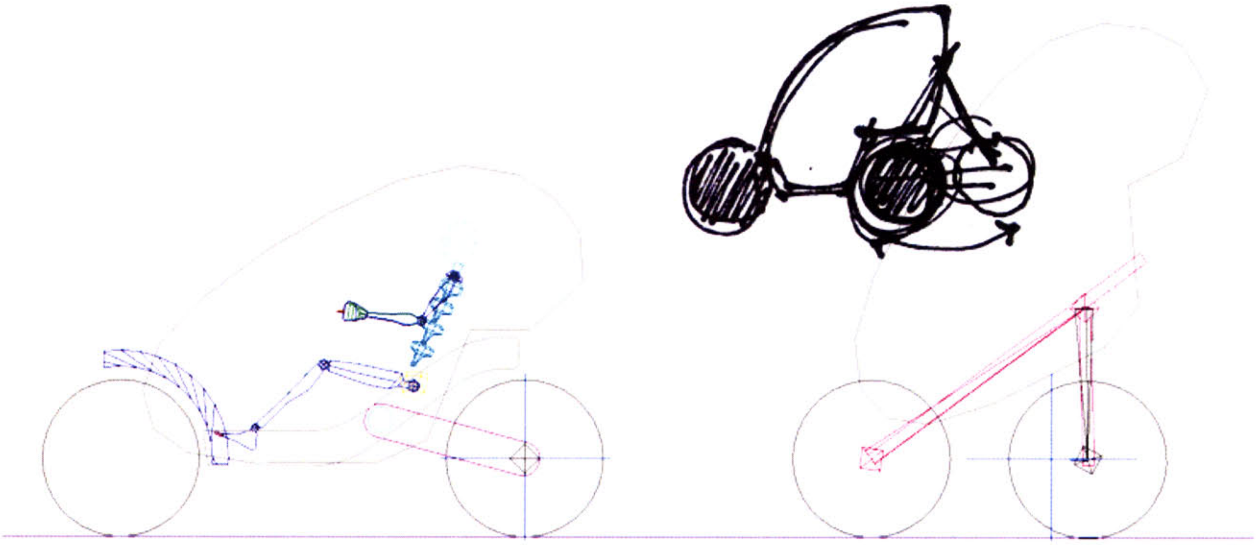


Fig 7.5
Hand drawn and computer sketches for a stackable vehicle

a distributed powertrain.

The design was sketched directly into 3D software capable of linking all the parts into a kinetic structure. This allowed to study the adequate placement of joints and the size and shape of each element so that they do not get in conflict with the folding mechanism.

Unlike the first design, which only achieved space savings by overlapping units into each other, this collapsing mechanism has two stages for gaining space: lifting the car up at a certain angle already reduces the footprint of each vehicle, but the same technique creates the space necessary for another unit to overlap a certain distance and further augment these gains.

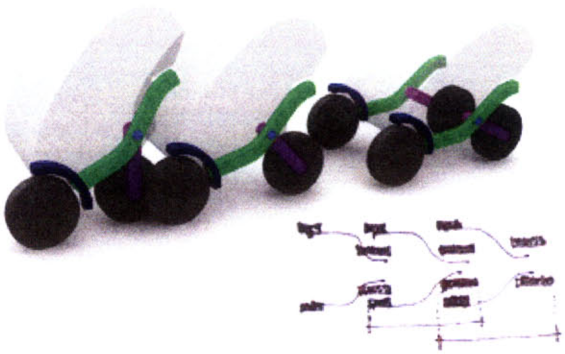


Fig 7.6

Volumetric study for a stackable car

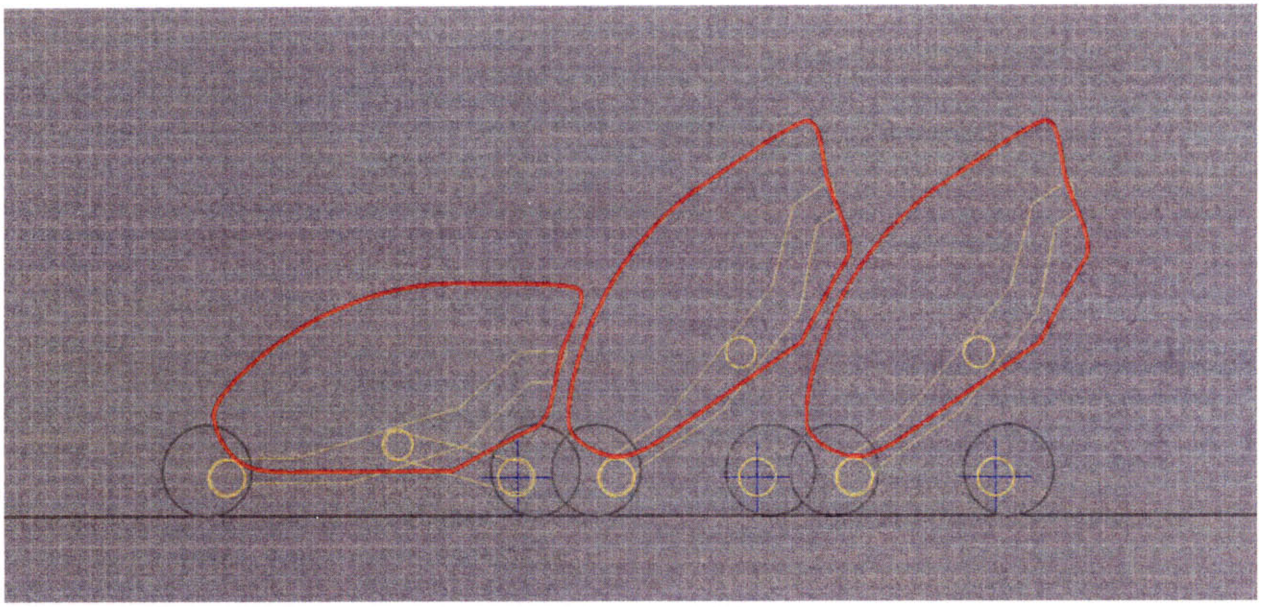
Now that the folding mechanism was already in place, the next step was to tackle the problem again of reducing as much unused space as possible, this time by getting units as close as possible to one another. The goal is to eliminate the interstitial space between cars, which in a traditional on-street arrangement can add an additional 40% to the size of the car space. When a single bit car starts the collapsing movement, the rear wheels move closer to the front wheels. If they keep moving forward, they would eventually touch the front wheels, so this is the limiting factor. In these schemes, the space saved was extraordinary because the footprint for a car can be virtually as small as the dimensions of two wheels put side by side (diagram). However, this movement forces the cabin to be lifted almost vertically, which generated two disadvantages: the traveling distance is much greater and the height of the car when it is parked is now a considerable factor.

One of the most interesting aspects of this exercise is the constraints in the design that are directly related to the nature of the car. The shape of the stackable vehicle, just like that of any other stackable product, is informed by a number of external references just as much as the relationship that needs to be established with another vehicle. In traditional vehicles, the overall geometry of the object is largely defined by the programmatic needs discussed previously as well as other external references, such as ergonomics, cultural stylistic preferences, etc.

In our case, there were three main constraints that informed the design of the stackable car. The first constraint was determined by ergonomics. That is, the relationship between the object and the human dimensional needs.
As explained in chapter 4, average car occupancy for all kinds of trips is below 2 passengers per vehicle. Therefore, when contemplating the design for an urban automobile, it was almost a natural choice to adopt a two-passenger scheme, with the sole purpose of reducing the required overall size of the car, and thus its footprint. The two passengers sit side-by-side. A front-back arrangement of passengers could would naturally reduce the width but would also increase the length and thus its height when the vehicle is tilted upwards.

Fig 7.7
Stackable chairs by Knoll

In addition to these concerns, a design of a stackable vehicle must be such, that it does not interfere with any other part of another vehicle when they are stacked next to each other. In modern cars, this relationship is largely ignored. The overall exterior geometry of a modern car is not influenced by the presence of another car, except in the case of some kind of collision. Indeed, bumpers, crumple zones and other features are designed to minimize the -usually violent and unexpected- relationship between the car



and another object (another car, a lamp post, etc), and protect the integrity of the unit and its content. When considering stackable designs, it necessary to offset certain parts of the object so that they do not interfere with other units and/or are able to interlock with other components. Stackable chairs, for example, use a tapered design so that the smaller end slides inside the bigger end of another identical unit. The actual shape and dimensions of the car are largely dictated by these constraints. A simple two-dimensional side diagram makes the relationship between each car in the stack to another and this relationship acts as a determining factor for the profile.

Similarly, from the top view, the interlocking of one unit to the next had to be considered. In this case, it was achieved by altering the separation of the wheels in the rear and front axle (although technically there is no axle), so that one of them would fit inside the other. Shopping carts have wheels attached to a tapered frame, applying the same principle to interlock into each other and create stacks of carts. The next chapter illustrates some of the

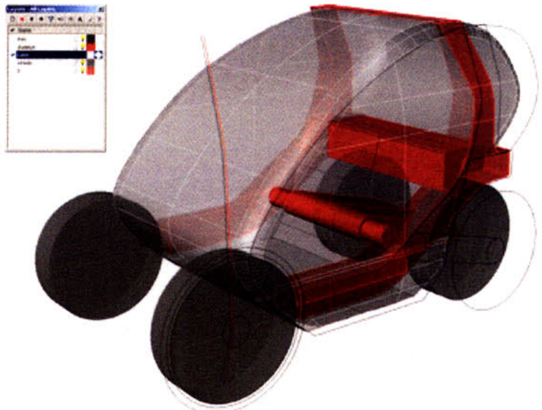
Fig 7.8

Side-view studies for the bit car

alternatives studied, including designs in which the two front wheels have a narrower separation that the rear wheels, but in the end it was decided that the rear axle would fit inside the separation of the front wheels. The actual presence of an axle represents an obstacle in these designs, because it limits the amount of possible overlapping. This can also be seen in more detail in the next chapter, but it can be summarized by saying that front and rear wheels needed to be grabbed from opposite sides (one internally, the other externally) or from the top in a caster-like design.

While the shape and dimensions are already largely determined by these two requirement (a two-person space and an interlocking body), the overall shape was streamlined to have a more aerodynamic profile. While this has mostly been a major consideration in high-performance automobiles and a practice more or less abandoned after the World War II, it has regained importance in recent times for a very pragmatical reason: a lower drag coefficient means less resistance of the body in the air, which translates in lower energy consumption to move the car.
Because of the technical complexities in this area, careful research needs to conducted in order to optimize the actual shape of the cabin, but that escapes the boundaries of this discussion. At this point, the design only aims for a single volume, with a very simple egg-like shape, pointed toward the front, and without kinks in the surface or protruding elements. The general premise of design seeks minimal intervention, with the object stripped down to its most fundamental features and rid of decorations.

Fig 7.9
Volumetric study for the bit car



When it was clear that the passenger cabin would move upward while the wheels (and the attached powertrain) remained on the ground, the idea of having an external frame that would connect these two components flowed naturally. This is not exactly an innovation either: most cars have a base structure called the chassis, which consists of an underlying frame plus the "running gear", which includes the engine, transmission, driveshaft, differential, and suspension. The chassis for a bit car is different because, instead of being a rigid element as in a traditional vehicle, it is collapsible. We also thought it would be important to make this difference visible and use it as another expressive element. The frame became known as the exoskeleton, only because it was externally visible, although technically, the analogy is not exactly accurate. Exoskeletons are external shells that protect the content of the interior; bodies that do not have an internal structure. So this term would be more appropriate for a monocoque bodywork.

The external frame is split in two major parts, joined by a hinge point approximately in the middle of the vehicle. The main structure grabs the front wheels and the passenger unit, while the smaller frame only connects the rear wheels to the rest of the car. The pivoting mechanism is simple. The rear wheels simply move forward while the front wheels are locked in place, thus pushing both movable components of the chassis closer to each other. Since both elements have rotational joints at the ends and one in the middle, the force applied in the structure pushes the middle articulation upward, and this movement tilts the cabin accordingly.

off road

the design of the bit car

The idea of a collapsible vehicle generated a line of research inside the Smart Cities group that would become known as the CityCar project. The research done within this project is now vast, encompassing many different aspects of urban transportation which have been undertaken by numerous students and researchers. The Bit Car was the first design known as the CityCar and it established a number of new premises.

Bit cars are small vehicles with the ability to collapse and interlock with another similar unit when not in used. This ability dramatically reduces the parking requirements. But this unique feature also created a very interesting question: once the user has placed

Fig 8.1
The bit car

his/her vehicle in a stack of cars, how is he/she able to retrieve it? The answer to this problem was simple. They are not. The ability to stacks cars to achieve higher parking efficiencies almost immediately suggested the creation of a fleet of vehicles for shared used, similarly to the way shopping carts are used in a supermarket. Users who need one simply take the first available unit. Based on these principles, many design variations are possible, and this proposal only presents one of them, but the Smart Cities group at the MIT Media Laboratory, under the supervision of professor William J. Mitchell, continues to generate more ingenious alternatives.

Bit cars are small electric vehicles for one or two passengers, designed for shared or public use in short distance trips in urban areas. They function on a shared-ownership model: users do not own one car in particular; they are members of a program by which they have access to a vehicle when they need one. At other times, bit cars are being used by other members. Their collapsible design directly contributes to this idea: when parked, bit cars are arranged in stacks throughout the city. These stacks act as "car dispensers", so users who need personal mobility simply pick the first vehicle from the stack and drive away. When they reach their destination, they return the car to the back of another stack.

Currently, most automobiles represent such a big expense for individuals that they are designed to fulfill almost any possible travel needs the owner may have. For example, a future driver who is looking into purchasing a car will be more inclined to get a larger vehicle able to carry at least four passengers, even if the likelihood of sharing the ride with someone else is extremely low. Since the cost must be absorbed for the product itself and not for the service it provides, it makes sense to invest in a car with room for more passengers than completely eliminating the possibility.

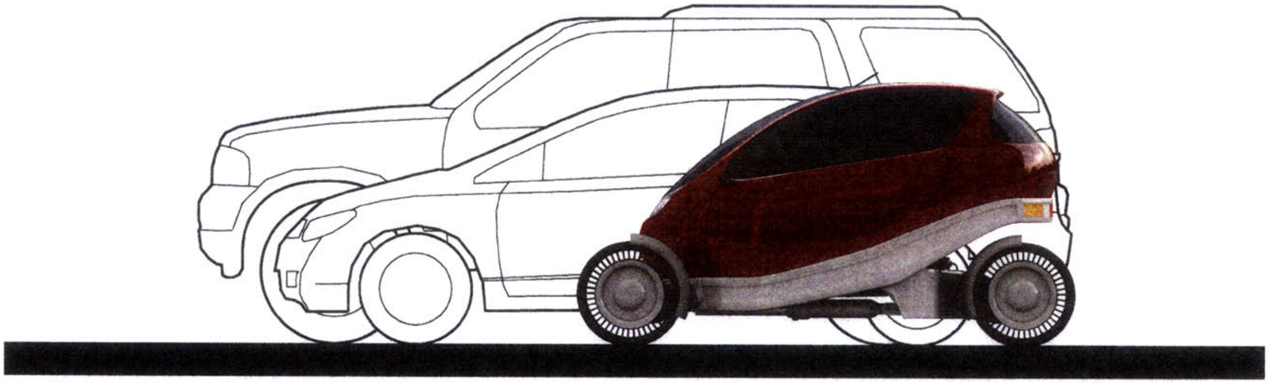
The CityCar proposes a completely different organization: a shift from a product-based to a service-based scheme. That means, drivers do not have to face a large investment upfront, but instead they pay for the use of the transportation service only. CityCars are not meant to be the ultimate solution for urban transportation. Much on the contrary, they are designed to cover one specific segment of the whole spectrum. That is, they are meant for short trips inside urban areas. These trips are generated by activities such

Fig 8.2
The bit car

as commuting to work, meetings, everyday shopping, etc. which account for the majority of current automobile-based travel in a city. Many other activities still require the use of other specific vehicles that would complement what bit cars cannot do. For example, trips to rural areas, or intercity travel need to be addressed differently, either with traditional vehicles or with new designs. Bit cars do not offer large storage space, so if a person needs to purchase a something unusually large such as a refrigerator or a sofa, a bit car certainly is not suited for this person. However, the argument is that this is indeed an unusual occasion. Most people do not drive every day to purchase a refrigerator, so when this or another special need arises, another vehicle with large cargo space should also be available, perhaps on a similar on-demand scheme. But the comparison is still unfairs since a conventional sedan would not be able to fulfill this need anyway.

As explained in chapter 4, today, parking spaces are determined by the so-called 'design vehicle', which is based on the dimensions of the 85 percentile of cars sold in the U.S. The approach of this work is to reverse this notion and design a vehicle based on

Fig 8.3
Comparison Ford Explorer, Honda Civic, bit car



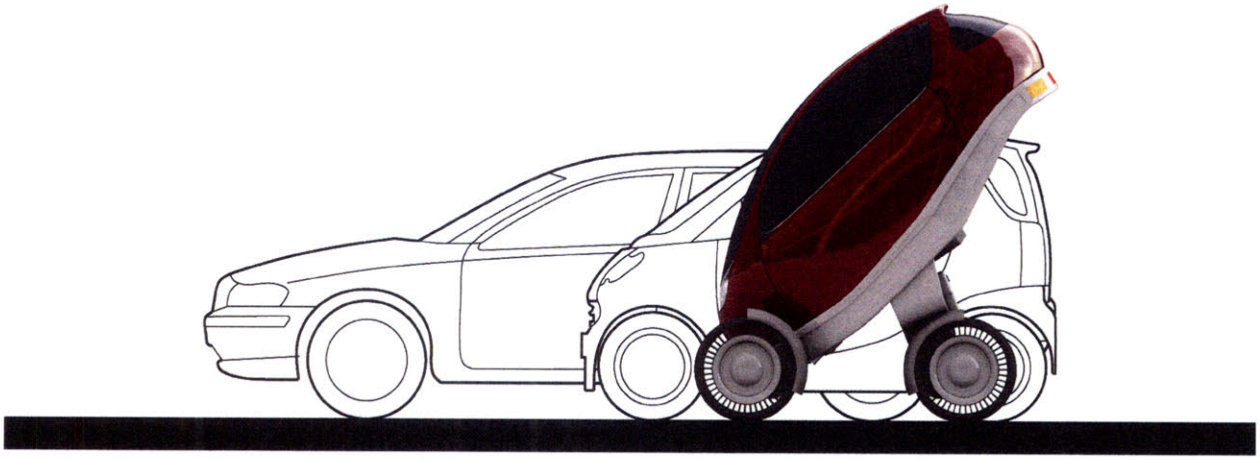
characteristics of the 85 percentile of city travel (figurately speaking), with the hypothesis that a car like that will radically affect the shape of the car and thus how parking spaces and other requirements are determined.

By reversing the traditional approach and limiting the applicability of these cars, it is possible to eliminate large inefficiencies that affect the use and the configuration of most automobiles today.

Bit cars accommodate one or two passengers with a small cargo space. While the height and width of a citycar is the same as a traditional car (passengers are still aligned sitting side by side), by eliminating the second row of seats, the length is reduced to 2.52 m, approximately 55% the size of a standard vehicle for 4 passengers. The SmartForTwo (by Smart, a subsidiary of Daimler) has already proven that ultracompact cars of this size are well suited for city travel.

The use of a small car to move around the city has some obvious benefits. The reduced footprint means more available space for other cars on the street, therefore alleviating some congestion. Even without the folding mechanism in

Fig 8.4
Comparison Volvo V-70, Smart ForTwo, folded bit car



place, if most of the automobile trips were made in small two-seater cars, parking space requirements could be slashed almost by half, further contributing to land availability for other purposes.

Smaller vehicles also weight less than big cars, and moving around a lighter body always requires less energy. So even with traditional internal combustion engines, the widespread use of lightweight cars in place of current automobiles would translate in better fuel efficiency. In fact, the SmartForTwo, which carries an internal combustion engine is able to achieve almost double the fuel efficiency of most four-door cars.

However, bit cars do not carry a traditional engine and drivetrain. One of the key elements that makes the design of the bit cars possible is the "robot wheel". And because robot wheels pack all the necessary components for the car to move inside the space of the wheel, the size and the configuration of the vehicle does not need to respond to the traditional three-volume scheme.

Structurally, they are formed by a lower collapsible frame that connects the four robot wheels to the passenger cabin. Robot wheels include a high-torque electric motor that is sufficient for the characteristics of most urban trips. It is often argued that the main disadvantage to implement electric motors in automobiles is the limited battery capacity, which results in a short range of operation for the car. While this argument is true, it is only valid for intercity travel and trips in rural areas, but the fact remains that the vast majority of daily trips is made of short distances (under 50 miles) and under low speeds (0-35mph). Current battery technology is already sufficient to cover these distances, so the problem is overcome by simply being able to recharge the car's batteries at the end of each trip. In this case, when bit cars are restacked at the destination point. Therefore, when stacks are integrated with the electric grid of the city, they also act as docking stations with automated recharging for bit cars (much like a the cradle for a wireless phone) and also eliminate the need of traditional service stations for refueling.

While this work is not focused on detailed specifications of the technologies included in the design of a CityCar, it is important to explain the benefits of these alternatives.

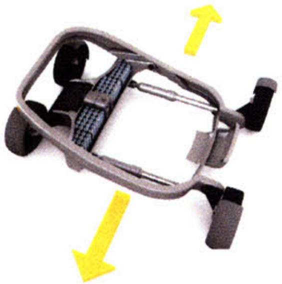
Energy efficiency is one of the main

Fig 8.5
Foldable chassis for the bit car

advantages of wheel-mounted electric motors. In current car configurations that use an internal combustion engine, there are multiple gears and transmission systems to make the wheels roll. Moving so many parts results in great energy losses. With wheel-mounted electric motors, the loss in energy transmission between the wheel and the motor is almost zero. This, of course, is a simplistic analysis because it does not take into account the generation of the electricity stored in the batteries that power the electric motor. In reality, the production of electricity in the US from burning fossil fuels also has substantial losses in heat, reducing the efficiency to about 35% in the best cases. However, bit cars with electric wheel robots and batteries are best coupled with alternative energy sources. Especially, with clean, renewable sources such as wind, solar and maritime power. But most of these sources are intermittent, so it becomes necessary to capture the energy when it is available and store it for use during overcast days, at night and when the wind is not blowing. So this also requires the use of some kind of battery technology. Additional energy efficiencies can be obtained through the use of wheel robots by regenerative braking. In conventional cars, differentials and gearboxes are not designed to transmit energy in two ways, but using electric motors directly attached to the wheels, it is possible to use them as generators any time the wheel is moving faster than applied drive frequency (that is, when the car is in motion attempting to stop). This energy can be stored again the batteries for later reuse.

Because electric motors do not produce harmful emissions, they are well suited for any environments so, for example, bit cars could restore personal mobility in older European cities that have banned the use of the automobile because

Fig 8.6 (opposite page)
Five driving modes with omnidirectional wheels



of environmental concerns.

The use of "robot wheels" also has two other important advantages. As demonstrated in Peter Schmitt's work, these wheels can be designed as modular units, with a standardized interface so that they can be mounted them directly to the frame. This reduces the number of mechanical parts to a minimum and allows for easy upgrade or replacement of defective parts in the propulsion system without the need of specialized technicians. The wheel in need of repair is simply unplugged and replaced with another unit, and it can be sent independently to the shop while the car stays in use.

Perhaps more importantly, they are capable of providing omnidirectional movement to the car, which also translates into higher efficiencies. The City Rover [chapter 6] was an early design exercise on the possibilities of an omnidirectional vehicle. At the time when the first version of the bit car was designed, the design of the robot wheel was still unfinished. Based on number of brainstorming sessions and movement diagrams by Franco Vairani, Peter Schmitt re-engineered a new robot wheel capable of rotating 125 degrees (between -35 to +90). As opposed to traditional steering, which only allows forward/backward movement and turning the vehicle by describing an arc, this range of motion enables five different driving modes:

☒ forward-backwards
☒ turning by describing an arc
☒ sideways translation
☒ translation at an angle
☒ rotating in place.

Omnidirectional movement has some substantial gains because it eliminates the space requirements of a conventional maneuvering, since the turning radius of a vehicle is reduced to its own footprint. U-turns and pulling back in reverse are no longer necessary because the car can completely rotate on the spot to turn its direction 180 degrees. Maneuverability is greatly enhanced, which should prove ideal for older cities with narrow streets and passages. Bit cars with robot wheels capable of omnidirectional movement can negotiate in tight situations or highly congested downtown areas. This also means that even outside a stack, a bit car can take advantage of interstitial spaces left in the city that other cars cannot use for parking.

The design of the robot wheel is further enhanced by combining them with Michelin's experimental tire known as "tweel". Tweels (combination of the words tire and wheel) have no inner tube and therefore they cannot burst or become flat. Instead, they use flexible polyurethane spokes to support the outer rim.
The argument is that these elements provide enough support and flexibility that they can take the role of shock absorption for the entire vehicle to the point that there would be no need for traditional suspension systems.

But undoubtedly, the most distinguishable feature of a bit car is its collapsible frame. It is made from two main elements. The larger component connects the two front wheels and holds the entire passenger cabin. This element is bent at the back to accommodate the other piece and the rear wheels. This smaller element of the frame connects the rear wheels and holds the battery pack as well as other small components. These two parts are connected by a main hinge point located approximately in the middle of the vehicle, which serves as the articulation to lift the car in parking mode. The two elements are also connected by two hydraulic actuators at the bottom of the unit, one on each side, roughly aligned with the rear wheels.

The battery pack is held by the smaller component of the frame, located in the rear. When the car is in driving position, the battery pack occupies the space underneath the seats. This is the largest available space that remains close to the ground in both positions, thus reducing the energy required to lift the car upward and keeping the center of gravity as low as possible. In parking position, when the cabin is lifted, the box protecting the batteries and other components is exposed and easily accessible for repairs, replacements, etc.
The change in position from driving to parking back to driving mode is performed by the two hydraulic actuators connecting the two elements of the frame. The dimensions of these actuators are XXX when extended (driving position) to XXX when contracted (parking position).

Robot wheels are attached to a disc that is also an articulated point. This ensures that the frame can rotate around (and thus lift up the cabin) independently, without affecting the axis of rotation for the wheels, which stays in place. In this fashion, all robot wheels remain fully operational and the vehicle is always fully capable of moving and maneuvering in both driving and parking positions.

The passenger cabin is a single-volume unit, but unlike a typical bodywork, it does not extend to cover the mechanical parts. The wheels, which include the powertrain, and the frame, which is the equivalent of the chassis in a traditional automobile, are pushed outside the cabin space. (find cars with wheels outside)
The passenger cabin is characterized by a large windshield that continues its

curvature to become a sunroof. Two windows that extend to the rear of the car to maximize visibility. The cabin needs to be a structurally sound element for safety purposes in case of an accident, so it may be solved as a monocoque construction, but aluminum and steel space frames or more traditional automobile construction are also a feasible option.
Because bit cars interlock with each other to form stacks, the front and rear of the vehicle should not be used as the main form of ingress or egress. Thus, bit cars have side pivoting doors like conventional cars.

There are many choices in the materials for in bit cars, and the design should ultimately respond to the specific needs of a region or a city where they will be running. However, it makes sense to use to use advanced lightweight materials throughout, even if they represent an additional expense. Carbon fiber, for example, could be the main component for the passenger cabin, because it provides high strength and durability and is lighter than the metal panels made of steel or aluminum commonly used for body work in cars. The McLaren F1 racing car features a carbon fiber monocoque chassis which not only supports the drivetrain but also serves as a very rigid safety cell. Carbon fiber is already in use in other high end vehicles (albeit mostly as body panels), and is also favored in other transportation applications such as boats and airplanes, in which weight reduction is a crucial factor. While carbon fiber is still substantially more expensive than other alternatives, the additional expense incurred by the use of these materials could be offset not only by gains in energy consumption but also by the increased use of each bit car because of their shared nature.

Inside, the dashboard is replaced by

three movable LCD touchscreens, with an adaptive interface that can be adjusted according to the situation as well as individual preferences. Some users may choose to display a map with the route while others may prefer more conventional information. Certain information that is critical to driving such as current speed and battery life (or range) should be displayed at all times.

A minimum number of buttons control specific -usually repetitive- actions that need to be triggered by the driver on quick notice (lights, locks, wipers) and the rest of the controls are accessible through any of the touch screens.

Because of all the new modes supported by the use of the robot wheel, the

Fig 8.7
Interior of the bit car

driving of the vehicle needs is probably best addressed with a different kind of controller than a traditional steering wheel. In this proposal, it is performed through a “virtual handlebar”, which consists of two joystick at each side of the seat that work together. The basic direction of the vehicle is controlled by moving the handlebar. With the push of a button on the joystick, it may be possible to access additional capabilities of the car, such as rotating on the spot or sideways driving. There are three handlebars, at each side of the seats (only one in the middle). The controller in the middle can be accommodated to be used in connection to the left or the right seat.

There is a small storage compartment behind the seats, but for additional space in the cabin, the seats can be completely collapsed in a horizontal position, when not in use by a passenger.

car pool

design evolution

Fig 9.1
The original bit car

After the initial design exercise of a collapsible car described in chapter 6, the first concept for an actual vehicle consisted of an exposed frame holding the wheels and the passenger cabin. The concept and design were developed in less than a week but contained all the basic ideas of what would become the premises for the city car.

The external frame is made of geometric shapes and clear angles, with a pivoting mechanism in the middle that connects the rear wheels to the main structure. The two front robot wheels are caster-like and grabbed from the top and rotate 360 degrees. The rear wheels are larger, not steerable and are connected to form a solid block in the back, with enough room in between the wheels to accommodate a battery pack, and a physical connector to another vehicle for recharging.

The cabin makes a sharp contrast with the frame by using very curved planes and lines, with large transparent surfaces. Geometrically, it is almost an extrusion of the side profile, with a rounded edge between the sides and the front which, in turn, makes the A and C pillars and roof structure.

Although the images were convincing, the design was hardly complete. In fact, the cabin was a little too small to fit comfortably a 6ft tall person, and there was little leg room. The doors were never fully resolved, and the side windows were not operable.

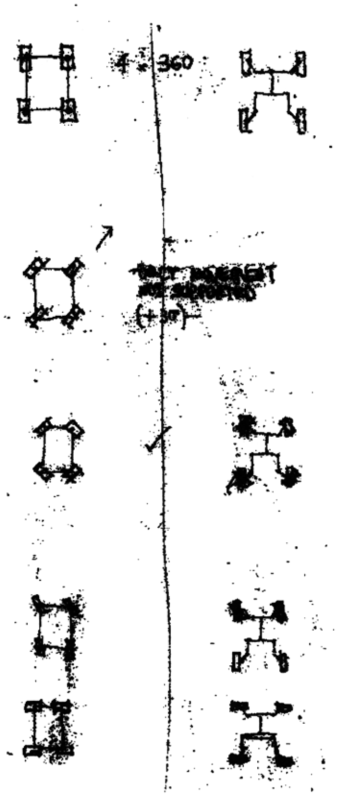
New beat

The second iteration was the result of a collaboration with Peter Schmitt. Peter Schmitt joined the Smart Cities group as a visiting student in 2004, and one of his first tasks was the re-design and re-engineering of the robot wheel that Patrik Künzler had originally envisioned. The work of Peter Schmitt is discussed in detail in his Master of Arts and Science thesis (2007).

Because we wanted to use the concept of modularity, we had to rethink the general configuration of the frame and provide the vehicle with four identical robot wheels, that could be easily interchanged, rather than two different sets as in the previous concept. The original concept had two smaller wheels in the front grabbed from the top, and two larger wheels in the rear attached to an axle. The rear wheels were non-steerable, and the two in the front were caster wheels, although the design was never fully resolved. This combination provided more maneuverability that a traditional car, but not the flexibility of movement that the city rover suggested (see chapter 5).
The main goal, of course, was to enhance the driving capabilities of the vehicle. The discussion was centered on how the wheels needed to be attached to frame. The diagrams show a comparison in terms of movement between four steerable wheels attached from the side and from the top.

The second goal of this exercise was to eliminate the outside frame of the original design and make a more conventional chassis underneath the body

Fig 9.2
Sketches comparing wheel arragenments for omnidirectional movement



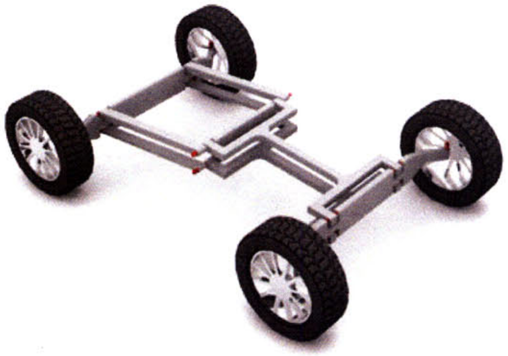


Fig 9.3 (above)
Foldable chassis developed with Peter Schmitt

of the vehicle. This is a more traditional approach in automotive design, whereby the cabin sits on top of a chassis or frame.

This means that the wheels are not fully omnidirectional in themselves, but they have clearance to rotate enough so that the vehicle can perform a full spin on its own axis. The argument is that fully omni-directional caster wheels can achieve barely anything more than this scheme, and any possible advantages do not correspond to actual useful situations that a driver might encounter. Normal driving, parking, highway driving, maneuvering in tight spaces can all be performed with an omni-directional car, but not it is not necessary to have four fully omnidirectional wheels.

The frame also has a pivoting point roughly located in the middle, and was designed to provide maneuverability of the car in both positions (driving mode or horizontal, and parking mode or vertical). To achieve this, the wheels must be attached to an element that remains horizontal even when the rest of the frame is changing positions. The scheme is similar to a desk-lamp and consists of two parallel tubes that move together, while the pieces in the front and rear remain vertical.

On top of the articulated chassis, a cabin was added, inside a dark grey

Fig 9.4 (below)
Foldable chassis sequence developed with Peter Schmitt

frame that resembled the first design. This external frame was attached to the chassis, but not connected directly to the wheels, and did not contribute to the collapsible function.

A major difference introduced in this second design is the position of the wheels in relation to the body. In order to minimize the footprint of the vehicle, the cabin overlaps the space for the wheels, so the body features two prominent cutouts in the front as a result of the motion envelope required for the omni-directional wheels. In the back, the body is recessed -as in the original design- giving sufficient space for the wheels to rotate. The motion envelope for the wheels requires

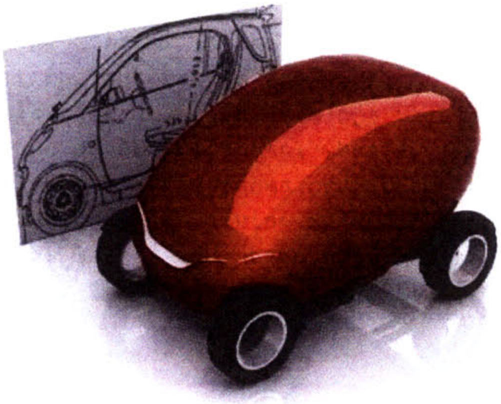
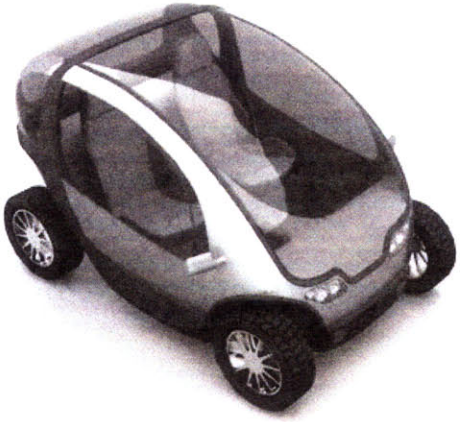


Fig 9.5 (left)
Volumetric study

Fig 9.6 and 9.7 (below)
Interior and exterior study



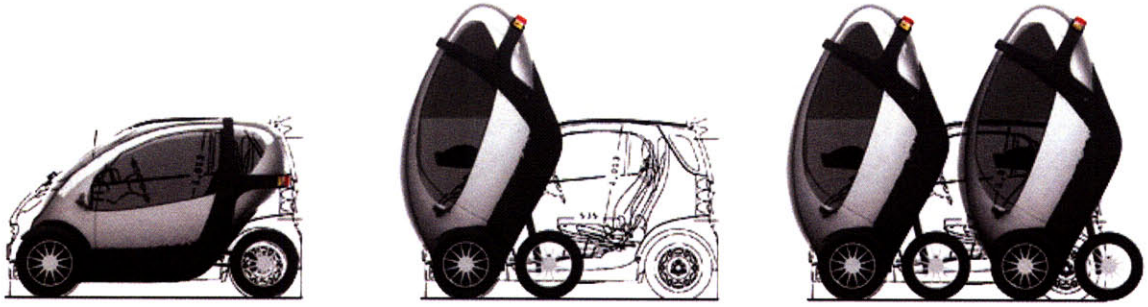
considerable space not only in the XY plane, but also in the Z direction, which is necessary to cover the travel distance when the suspension mechanism of the wheel absorbs differences on the ground plane.

This car had the front and rear wheels aligned, just like a traditional car, and the front of the car was closed, which meant that there was no space interlocking or overlapping with another car. To compensate for this, the dimensions of the frame and the pivoting point were designed so that the cabin would end up almost vertical when the vehicle is collapsed, thus reducing the required footprint substantially. The end result of folding the cabin so much was a similar footprint as a folding and stacking combined in the previous scheme.
As an added benefit, the stacked cars could be removed from any location in the stack, since there is no overlapping.

Sport Bit

After a number of iterations, the cabin was reshaped.
One of the main issues was a necessary adjustment to the side windows and doors. A conventional solution for a

Fig 9.8
Folding sequence study



door was adopted so that the window could be lowered to give natural ventilation to the interior. For this, it was necessary to break the continuity of the cabin, since the window needed to lay on a different plane so that it could go inside the door when lowered. At the same time, the surface of the window needed to be roughly the same

Fig 9.9
Exterior profile study

Fig 9.10
Final configuration of second version

size or smaller than the lower portion of the door where it fits.

The result of the second iteration has the look of a more traditional small car. Wayne Cherry, former head of design at GM, pointed out that it was something we could expect to see at the Tokyo auto show.
A great deal of this is owed to the fact that it has many traditional details: although it still has no front volume (hood), the wheels are somewhat embedded in the body of the car, and it is outfitted with conventional details, such as a side view mirror, traditional headlights, fog lights, a "waistline", and most importantly, conventional doors that can be opened and operated.

City Pod

The third iteration of the BitCar is a reaction to the conservative approach taken in the previous stage.
Among the elements that were changed in the second scheme was the interlocking scheme of the cars when parked. However, we felt that this feature was one of the key aspects that gave a strong identity to the project. Therefore, after a few brainstorming sessions, it was clear that it needed to be restored.
The other main intention was to eliminate much of the conventional details and explore different expressions for a vehicle. In other words, we wanted to make something that did not resemble so much like a conventional automobile. This was a tricky decision, because we now brought into play a semantic discussion to the table. What are the elements that define a car as a car? Should the wheels be exposed or completely hidden under the body? Is it a good or a bad thing that people associate the design with the concept of a car?

Fig 9.11
City pod study

Because our methodology insists on "doing" over discussing these questions, we simply made a number of design decisions:

*eliminate A-pillar, making the cabin more like cockpit of a jet
*eliminate headlights. lighting would be done through tiny LEDs embedded in the skin
*eliminate side-view mirrors. cameras inserted in various points of the body would capture the surroundings and display these views on the screens.
*expose front wheels, moving them away from the space of the passenger cabin as in the first iteration
*the frame had to be eliminated completely or reshaped to regain its importance and function within the overall design.

This last point was the first to be addressed. The frame could not stay as a decorative element without any function. Structurally, the main difference between the first design and the second is in the way that the wheels connect to the chassis. For the second version, all four wheels are grabbed from the side, and none from the top. We still felt this was the best solution, because even in caster-like wheels, ultimately the wheel has to be attached from the side. It was also important to maintain the omni-directional capability for the vehicle and this was a convincing solution.

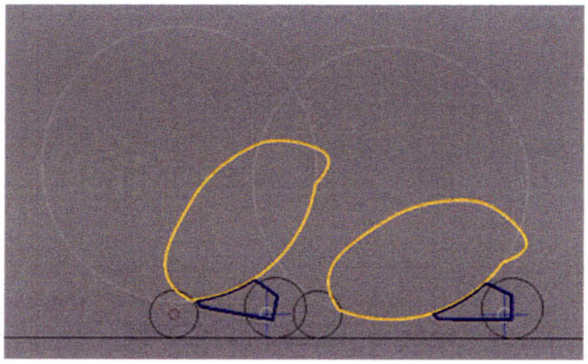
In the second design, in order for the wheels to be steerable in parking mode, it was necessary to introduce an element at both ends of the frame that would always remain vertical. This created a number of complexities that, in the end, needed to be solved through an additional sliding mechanism to would ensure that the movement of the wheels is restricted to the horizontal plane. To avoid this complexity, we replaced

Fig 9.12
City pod study

the hinge point connecting the front and rear components of the frame with a sliding scheme between them. The rear element, then, adopts a wedge-like shape, so that it slides horizontally under the front element pushing it upwards.
In reality, the plane diving these two elements is follows an arc, so the sliding mechanism is basically the same principle as the central hinge, but in this case, the pivoting point is moved well outside the space of the vehicle. The design of both elements of the frame responds directly to the shape described by this movement, resulting in a much more curvilinear series of elements than in the first frame.

The next design move was to eliminate the A-pillars. We wanted to have as few

Fig 9.13 (right)
City pod sliding and stacking sequence



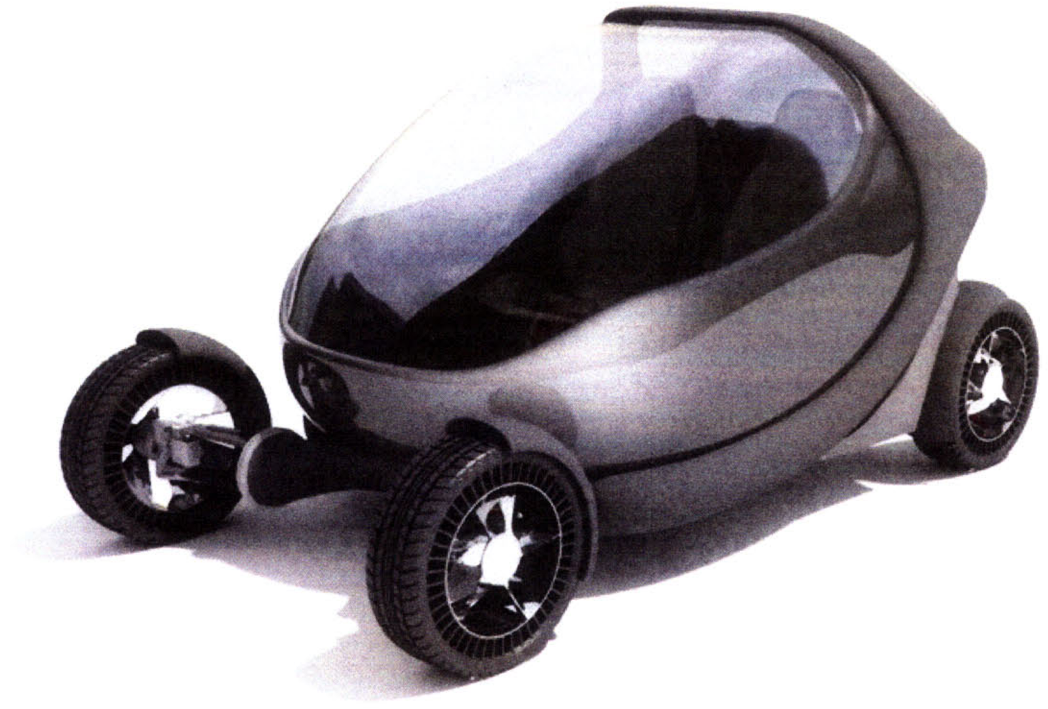
elements as possible and A-pillars created an important interruption in the flow of surfaces. This move had a number of implications that needed to be carefully considered.

The windshield is a crucial element in the design of cars because it acts as the filter to the driver's vision, which is the main input of information to control the vehicle itself. In order to eliminate any divisions on this surface, it is also necessary to replace the side doors as the points of ingress/egress. Whenever there is a side door, the partition line of the surfaces (so that the door will open) will require, at the very least, some element for weather insulation. Even if this break line is not a structural component to support the roof, the material for weather proofing will interrupt the transparent surface creating the equivalent of an A-pillar.

So if we wanted to have a single continuous surface to go uninterrupted

Fig 9.14

City pod in its final version



from one side of the car to the front, and finally to the other side, ingress and egress could not be solved through conventional doors. By having no A-pillar in place, the windshield becomes a single element with a similar look of a fighter jet cockpit. Since this transparent element is not divided, it must be moved (by lifting, rotating or sliding) to give enough space for the passenger to comfortably get in and out of the vehicle. After some revisions, it was decided that the cockpit would be fixed at the front, and pivot around a point close to the center of rotation for the cabin. A comparable design was adopted for the Aero concept car by Saab.

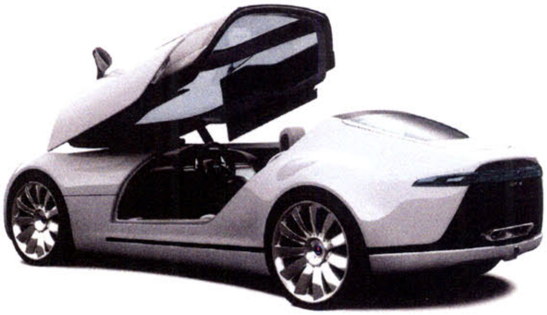


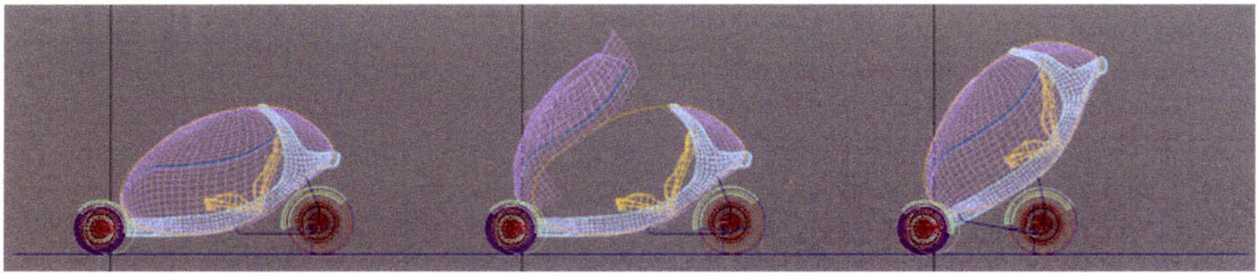
Fig 9.15
Saab Aero

Naturally, this new cockpit needed to be a continuous element, so the overall shape of the vehicle is noticeably more curved than all other previous designs.

The front wheels were also moved to the front, outside the space taken by the cabin. The motion envelope for the front wheels does not interfere with the body, so there are no cutouts in the shape of the pod.

The robot wheels correspond to the most up-to-date version designed and engineered by Peter Schmitt for his Master of Arts and Science degree at the MIT Media Lab. The suspension of the wheels is not embedded anymore (as in the first two designs made by Patrik Künzler and Smitt respectively) and instead it uses a double wishbone

Fig 9.16
City Pod opening sequence



scheme, that also constitutes the attachment element to the main frame.

The rear wheels are also grabbed from the side to the sliding unit that pushes the frame and cabin upward. This piece moves along two rails that define the curved plane. From the top view, these rails are not parallel, but form a V-shape, getting closer to each other toward the front of the vehicle. When the car is in driving mode, the front and rear wheels are aligned, but when it the car lifts up to go in stacking mode, the rear wheels slide in a motion that drives them forward but also inwards. This way, when the car is in parking position, the rear wheels are not in line with the front wheels, and this offset allows for the interlocking and stacking of the vehicles one behind another.

XityCar

The fourth generation of the bit car is a return to its origins. After all the changes introduced in the third version, the pod was probably too different from the accepted image of a car, and raised more questions than answers.

The principles are still the same: four robot wheels attached to an exposed frame that holds the passenger cabin. For this version, we decided to keep the frame with the sliding movement developed for the previous scheme, but change the appearance of the passenger cabin from the cockpit look to something more like what had been done for the first bit car.

So the passenger unit has very similar proportions to the original design, but it has been lowered and stretched to provide considerably more interior space, which had not been adequately dimensioned at that time.

Fig 9.16
Xity Car sliding chassis

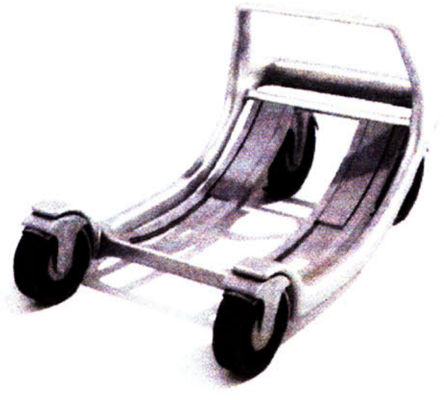


Fig 9.17
Xity Car exterior and interior studies

Ingress/egress to the car is again solved through conventional doors on the sides. This brings back the A-pillar. At the lower end of the A-pillar, on the front, there are conventional headlights.

The frame has also been lowered on the sides, giving enough room for the side door, but it is also curved as in the previous iteration because the collapsing mechanism still consists of a sliding element in the rear that pushes against the front element.

This design explored both possibilities for grabbing the wheels: from the sides as in Schmitt's latest design for the robot wheel, or from the top. The main problem with grabbing the robot wheel from the top in a caster-like fashion was all the extra travel space required above the wheel for suspension, plus all the components for steering and support which, in the end, created an awkwardly high structure.
But the utilization of Michelin's Tweel technology mentioned in chapter 8 would provide a convincing answer to this problem.
It is argued that tweels are capable of enough deformation and support that provide all the suspension necessary for the vehicle. This means that they do not require any kind of shock absorbers or wishbone configuration, since there is no vertical travel space required for the wheels which, in turn, allows for a very snug fit of a caster-like design.

Analysis

Our methodology encourages finding solutions by repeatedly testing several alternatives. These design studies allow for comparative research, and evaluate them in various aspects, including functionality, aesthetics, materiality, and so on.
The design decisions are made based on a number of variables, so rarely ever there is a perfect solution. Most of the times, one design move affects another decision.

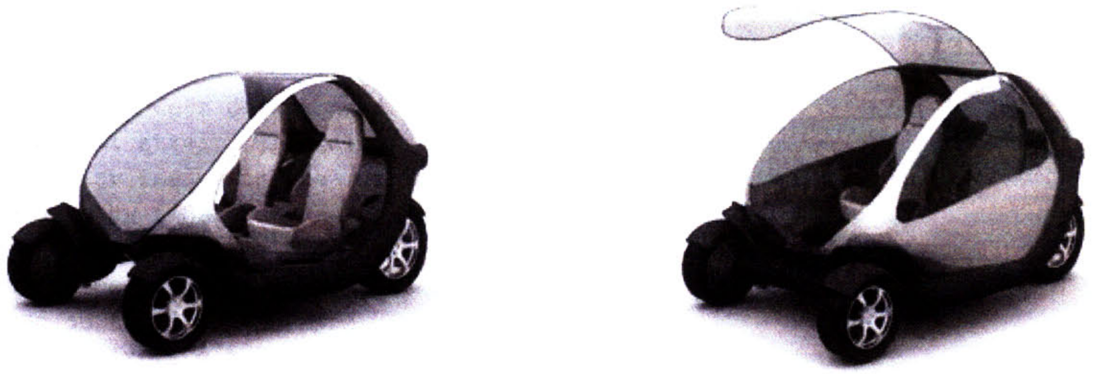


Fig 9.19 and 9.20
Ingress/Egress studies

The issue about ingress/egress is a clear example. The final design of the bit car features side doors for access, but entry from the front and the back was also studied. Front access offers and interesting possibility, because vehicles can park directly against the curb and passengers do not need to step on the actual street. They also account for a smaller footprint when cars are parked side by side, because the gap between vehicles can be reduced to a minimum since there is no circulation required on the sides anymore. Front access facilitate egress but creates difficulties for entering the car because the person must rotate before seating. This could be an awkward movement if the seat is inside the vehicle. On the other hand, if the seat is pushed outside by an automated mechanism to facilitate seating, it becomes problematic on a rainy day. On the other hand, side access is equally convenient (or inconvenient) to get in and out of the vehicle, and because the seats always remain inside, they car is somewhat protected of the weather when the door is open. Because side doors are by far the most common implementation, they are regarded as a more conventional approach, whereas front access can appear as innovative. Front-acess doors need also to be carefully designed so that the swing angle is not extreme and it becomes impossible for a person to reach and close the hatch. Otherwise, the car must have an automated procedure to do so. Most importantly, all swing doors require additional empty space to be operated. In the particular case the bit car, when stacked, the space in front is taken by another unit, so it is not possible for people to actually interlock the vehicle into the stack and get out. Side doors, on the other hand do not have this problem and that is the main reason why they were chosen.

One of the most discussed options in the design of the bit car was the placement of the wheels in relation to the body. In the end, it was decided that they would not be part or somehow embedded in the overall volume, but they would be slightly outside as an independent object. An open front with wheels extending outside the passenger volume presents the challenge of not having a

Fig 9.21 and 9.22
Open and closed front studies

crumple zone as a safety feature. It must be noted that this issue remains largely underdeveloped in this project. The subject of passenger safety in collisions is a research area too large to undertake for this concept, but we believe alternative solutions are feasible. For example, the concept car dubbed "Nido" by Pininfarina shows a different approach to safety for small cars which may be applied to the bit car. In the Nido car, chassis and passenger unit are also independent from each other and connected through deformable elements (springs, honeycomb structures, plastic foam) that absorb and dissipate the energy in case of a head-on collision (figure 444).

Fig 9.23
Pininfarina Nido safety concept

Another series of design studies included versions of at least two very different collapsing mechanisms: folding versus sliding. There are still not clear advantages of one scheme over the other. However, in order to keep the folding structure stable, we included a hidraulic actuator, which in the end, is a sliding mechanism. So, in fact, the proposed design features a combination of these systems, but since the main elements of the structure pivot around a hinge point, we regard this option as a folding mechanism.

Still open to debate is the question on how to attach the wheels to the frame-chassis. Conventional cars have a

Fig 9.24 and 9.25
Pivoting and sliding mechanisms comparison

horizontal axle and the wheels can rotate +/- 30 degrees in each direction to provide steering to the vehicle. For bit cars, we had decided that omnidirectional movement would be a crucial factor in the design, so a standard axle is just not adequate. One of the options consists of attaching the wheels from the side (either interior or exterior in relation to the volume of the car) at an angle, so that there would be enough clearance to rotate the wheels a total of at least 300 degrees. The City rover concept described in chapter 5 uses this technique to give omnidirectional movement to the pod. This idea has been implemented in a number of different vehicles, most recently in the Jeep Hurricane concept shown at the Detroit auto show in 2005.

The second option is to use attach the wheel from the top to a fixed point in the frame through an arm (usually a fork) that rotates with the wheel itself. The arm is then fixed to a rotating joint for steering, allowing the wheel to rotate freely 360 degrees. This creates a caster wheel. Caster wheels typically require some kind of structure above the wheel to house the steering joint plus additional space is required for vertical travel in the suspension mechanism. A major disadvantage of caster wheels it that they suffer from flutter, which makes the wheel itself swing rapidly from side to side and could result in losing control of the vehicle. However, they still offer the possibility of creating interesting traffic patterns since vehicles with caster wheels are capable of changing directions almost at any point. Side-grabbing also has some disadvantages. First of all, the wheels do not rotate freely as caster wheels do: there are certain angles that cannot be achieved because the wheel collides with the arm, but after a comparison of both schemes, we concluded the

Fig 9.26
Jeep Hurricane 2005

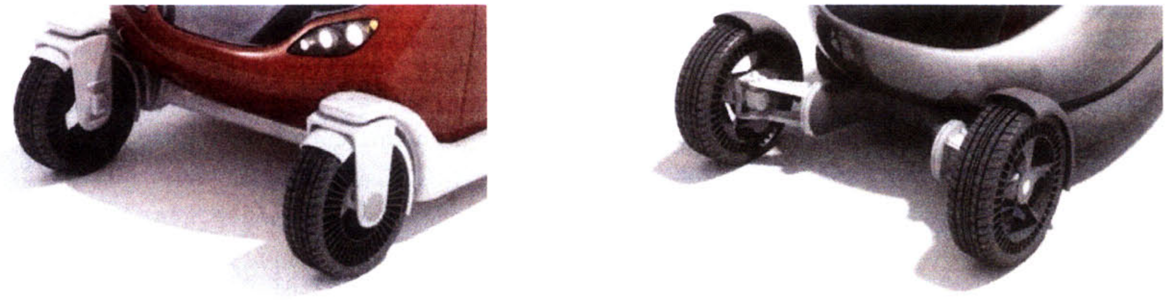


Fig 9.27 and 9.28

Caster-wheel and side-grabbed wheels study

difference in movement patterns for the vehicle as a unit was not substantial. Furthermore, some of the additional types of movement that could be achieved through caster wheels do not seem compatible or necessary for city travel. For instance, the ability to switch from forward to sideways translation at high speeds could prove useless since the driver is not facing the direction of travel after the turn. Additionally, a side arm to hold the wheel in place creates a short axle-like element that could become an obstacle in the design of the stack, whereas a wheel held from above leaves more room next to it for interlocking one unit after another. The use of caster wheels in automobiles is another topic that could lead to future research, but for the final configuration of the car, it was decided to use a scheme that grabbed the wheels from the side. As mentioned before, the scheme corresponds to the components designed and engineered by Peter Schmitt, who developed the latest iteration of the robot wheel.

Another topic that was subject to constant evaluation and will remain open for future designs is whether cars should interlock with similar units to create stacks or not. The second version of the bit car eliminated the interstitial space between units but the did not overall their footprint at all. This scheme has the benefit of being able to remove any unit from the stack by sideways translation, and cars in fact, do not need to be arranged in stacks anymore. This design, of course, eliminates one of the opportunities to save space so, in order to achieve the same density, cars must be smaller or they need to be lifted higher (closer to vertical position). Although the difference is not substantial, this demands taller spaces for stacks. At the same time, vehicles must be carefully tested with weight to prevent them from accidentally tipping over. While the topic remains open to debate, the final decision was made on the basis of the identity of the concept. The image of the initial version of the bit car was so strong and recognizable that it became known as the "stackable" car, exactly because each vehicle would interlock with others. This was also the stem for many other ideas such as sharing vehicles, organizing cars in stacks, etc.

Fig 9.29 and 9.30
Interlocking and non-stacking parking study

double parking

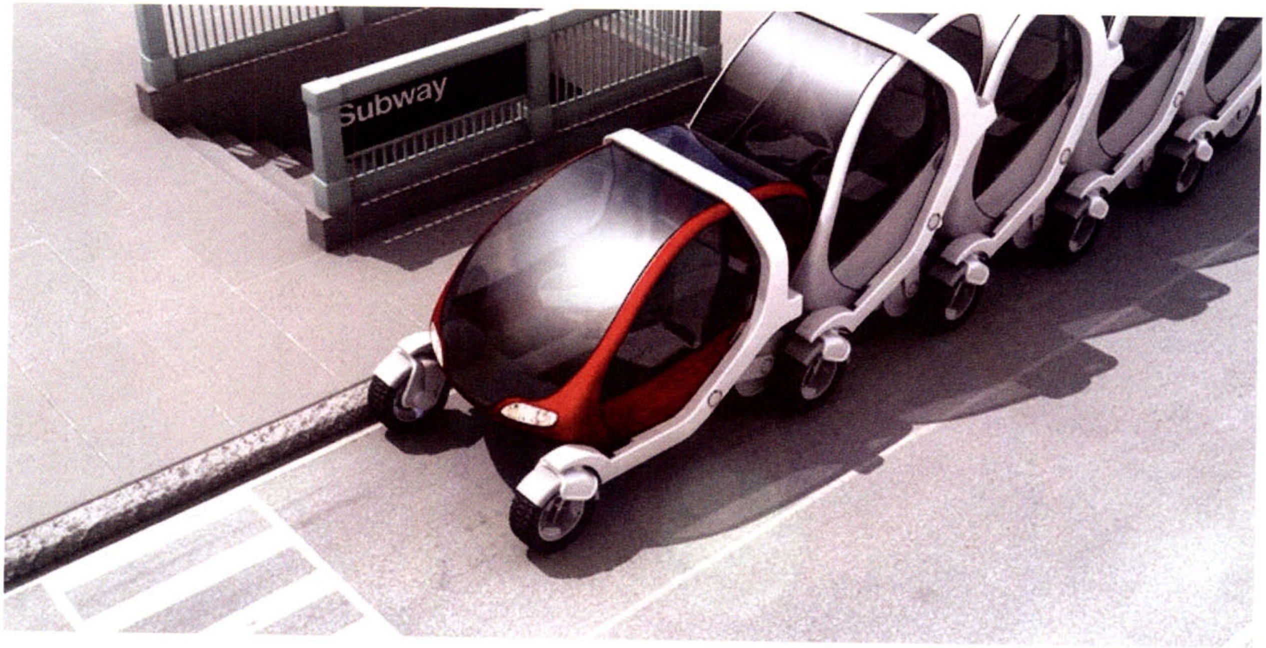
more than just one car

This proposal is not an exercise on styling or a simple reconfiguration of the automobile. Citycars are more than just a car. Citycars are designed to function as a system, presenting a new method in the transportation network of urban cores.

They aim for a spot somewhere between mass transit systems and private automobiles, offering public transport in combination with personal mobility. They are meant for a specific use only, that is short trips within urban areas,

Fig 10.1

Stack of bit cars next to a subway stop

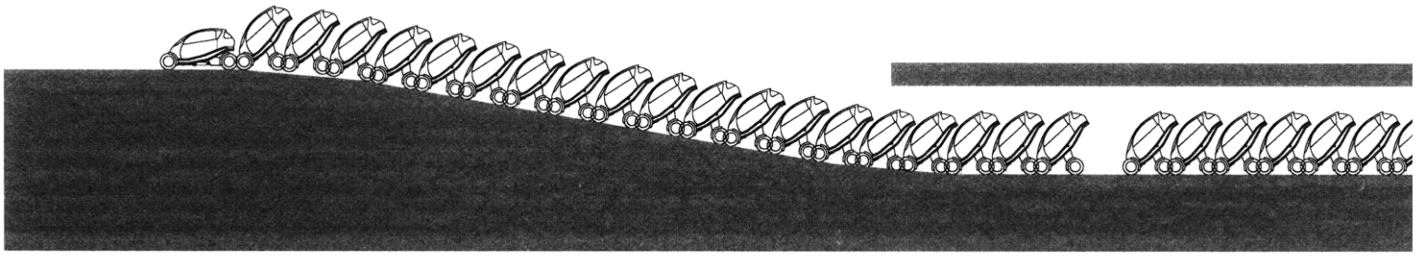


so they would not replace the entire automotive fleet of a city, but they could potentially offer an advantageous alternative to a large number of privately-owned automobiles that are currently fulfilling the need for personal mobility.

Design of stacks

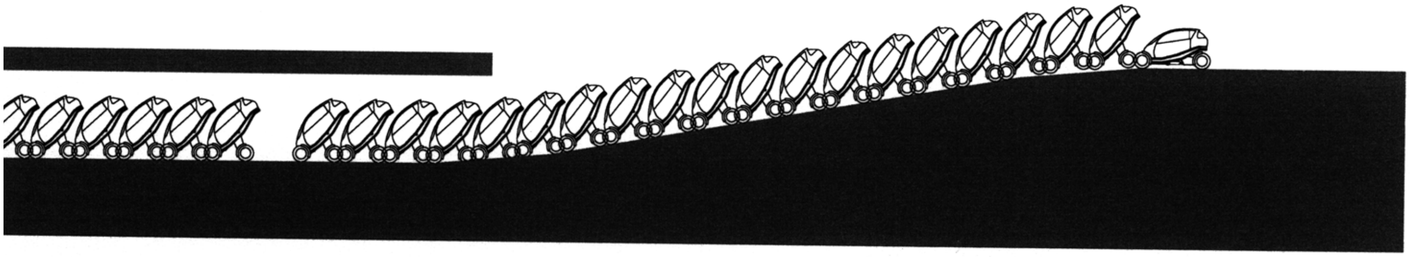
Citycars save substantial parking space by stacking one behind another, but this feature has additional benefits. The first car of the stack then connects to the electric grid of the city by a simple automated hook. In the future, when the efficiency of wireless energy transmission systems increases, City cars could greatly benefit from this technology. In the meantime, a reliable automated plug-in mechanism would be sufficient. It is important that these connections be weatherproof and safe, but also that they be fully automated so the user does not worry about refueling -or in this case recharging- the car. It must be all part of the system.
All other cars behind the first car in the stack would not hook up to the electric grid directly, but to the back of the car in front of them. This means that the recharging mechanism in the car must be capable of two kinds of connections: one directly to the infrastructure (the plug on the street) and one to the car in front of it. Each car, must have one connector. The process of hooking up to the car in front must also be automated and

Fig 10.2
Underground stack dispenser of bit cars



activated with a proximity sensor, without any actions from the user. Other schemes that do not require a connection between the vehicles are also possible, but carry a disadvantage. If each vehicle has to connect to the electric grid independently, then the infrastructure required is somewhat larger and not nearly as efficient. In the case of on-street parking, it would be necessary to provide charging points (either by induction plates or wired connections) for all bit cars that may possibly park at that location, in a distribution similar to parking meters. However, if bit cars connect to other bit cars to recharge, then only one charging point is required, and the number of cars in a single stack does not need to be predetermined.

Because citycars need to be recharged, there will always be some minimum infrastructure required. Much like stops in transit systems, these points can range in their complexity from a simple automated hook on street next to the corner of city block to sophisticated facilities that function as car dispensers. These facilities may offer different levels of service, including cleaning, scheduled maintenance, upgrades, repairs, etc. in addition to parking and recharging.
In situations where several bit cars are stacked in a single formation, the line should be interrupted for the length of at least one car in driving mode, so that it is always possible to remove any unit from the stack by driving sideways.

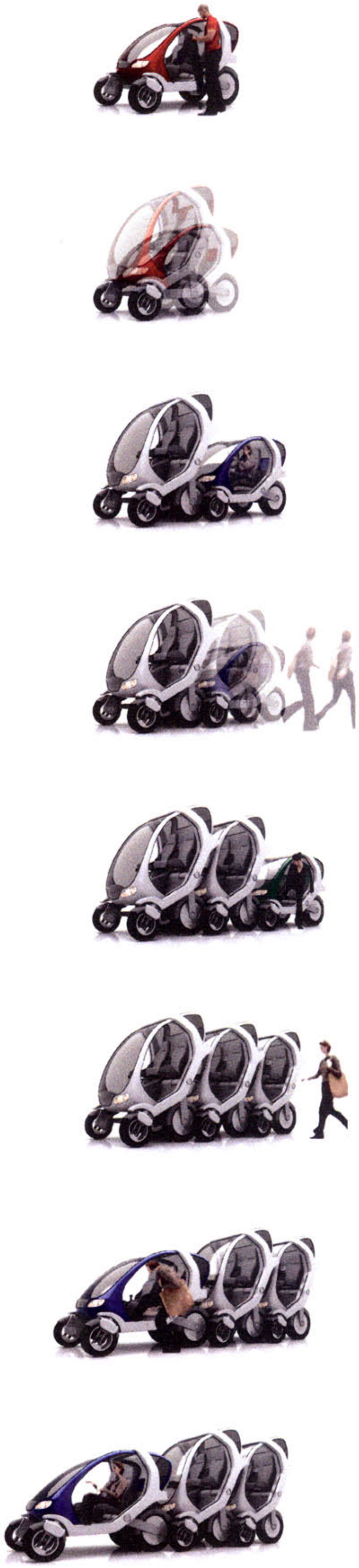


These facilities may be integrated as part of a building, or built under ground and become nothing more than technical space.

Fig 10.3
Bit car stacking sequence

How do city cars work?

When a user needs a citycar to move around the city, he/she walks to nearest stack. Stacks are easily accessible, located in many street corners, next to airport terminals, subway and bus stops, residential and office buildings, supermarkets and malls. Sometimes, a stack might not be in sight, but all citycar stacks can also be located through the use of any device with access to the Internet, especially useful in handheld devices such as cell phones and PDAs. The system will inform the user of the nearest locations, with availability of cars and current pricing for each stack. As travel patterns vary greatly according to the location and the time of the day, demand for transportation also fluctuates, so the availability (supply) should follow these variations with dynamic pricing. Real-time information can help the user make the best decision.
Unlike car-sharing systems that rent units by the hour, advance reservations are not necessary and they are not encouraged. If CityCars are locked up taking parking space for long periods of times, they neglect the gains of a shared-based system. In some cases, however, users might need to briefly get out of the vehicle, make a quick stop and continue driving. So CityCars may be locked for short periods of times, which is especially useful if there are no stacks in the vicinity. An adequate pricing scheme for these situations should also be in place to prevent abuse and keep as many citycars as possible always in circulation or available to other people.



Once the user has located and walked to the stack of cars, an electronic system identifies the person and gives him/her access to the system. There are several options for this. A rechargeable RFID card may be tapped on a reader located on the front of each CitycCar to unlock the vehicle. Cities may combine the collection of fares for multiple transit systems with the same access card so multimodal transfers between, for example, the subway network and a citycar are seamless. The procedure for fare collection, however, does not need to be run by the city or even by the same operator that manages CityCars. Swiping your credit card may also be an option but it requires a credit card reader to be embedded in the car, or a special machine similar to a parking meter to be mounted on the sidewalk. But credit card, banks and other financial institutions also offer service for fast payment through the use of contactless cards, which still provides the citycar operator with identifiable information about the user as well as the appropriate transaction fees. The system may also be combined with cellular phone providers. Entering a combination of numbers communicates the management to remotely unlock and release a vehicle for driving, and your citycar charges may appear in your cell phone bill.

After the system has successfully approved the transaction, the first car of the stack, which has been in the queue the longest and is now fully charged, is then lowered from parking to driving position. The vehicle is unlocked and the driver can open its door and get inside the car.

Because the system has already indentified the driver, electronic components will adjust themselves to his/her preference. The possibilities for user customization can vary greatly depending on the technology available, and enhance the driving experience considerably. As a starter, since the driving control is electronically processed by a computer, different options for driving syles can be implemented through software. Despite some limiting parameters such as tire friction, vehicle weight, etc. that are specific to each car, drive-by-wire technology is capable of emulating the handling characteristics of other vehicles, so users can download and apply a different driving profile to the car based on their preference. A young driver may want to feel like driving in a sports car with a manual transmission while his grandmother may prefer to automate the driving as much as possible. At this stage also, users may enter their destination through the use of a keyboard or a touchscreen or speaking into a voice-recognition software, and the onboard computer will provide with route alternatives, traffic information, location of stacks near the destination and the estimated price for the trip. Drivers can use these tools to plan their trip and control their budget accordingly.

Once all driving parameters are loaded in the computer and the driver is seated in position, the car starts an automated process to disengage from the stack. The first car of the stack is connected to the power grid and to the second car of the stack as well. All other cars are connected to the car in front and the car behind, so that there is a flow of electric current to recharge all vehicles. Before the user drives away to his/her destination, the connectors in the first car must retract and unplug the car from the grid and the stack.

Just like in a vending machine, after the first car is released from the stack, the second car must now take its place, so the entire queue stays always in place. This procedure must also be fully automated to ensure cars are in the same location and fully charged when they are needed. Then, all citycars in the stack simultaneously move forward the length of one folded vehicle and the new first car reconnects the entire stack to the power grid to continue recharging all units.

In the meantime, the driver and the bit car are already on their way to their destination. Thanks to real-time traffic monitoring systems and on-board software that maps out this information, drivers can choose which route will provide the shortest driving time or distance.

Once the car is approaching the destination point, screens will display directions to the closest stack of cars, or the chosen one if different. The final cost of the trip may come down on the availability of spaces and distribution of cars. So some drivers, for instance, could choose to return the vehicle to the second closest stack and get a discount on the tag price of the trip if the first choice is in high demand.

When the vehicle reaches the stack, the user simply drives the car into the back of the last car of the stack. A proximity sensor will detect the distance to the car in front and, when they reach a threshold, the on-board computer will take control from that point. An automated procedure simply ensures that the wheels of the incoming bit car are properly aligned with the car in front and prevents a collision with the rest of the stack. After aligning the car, the CPU drives the car forward to interlock with the next car and connect to the power chain. Once the car is connected to the rest of the stack and ready to begin charging, all electric motors are shut off and the passengers may exit the vehicle. Another set of sensors in the interior of the

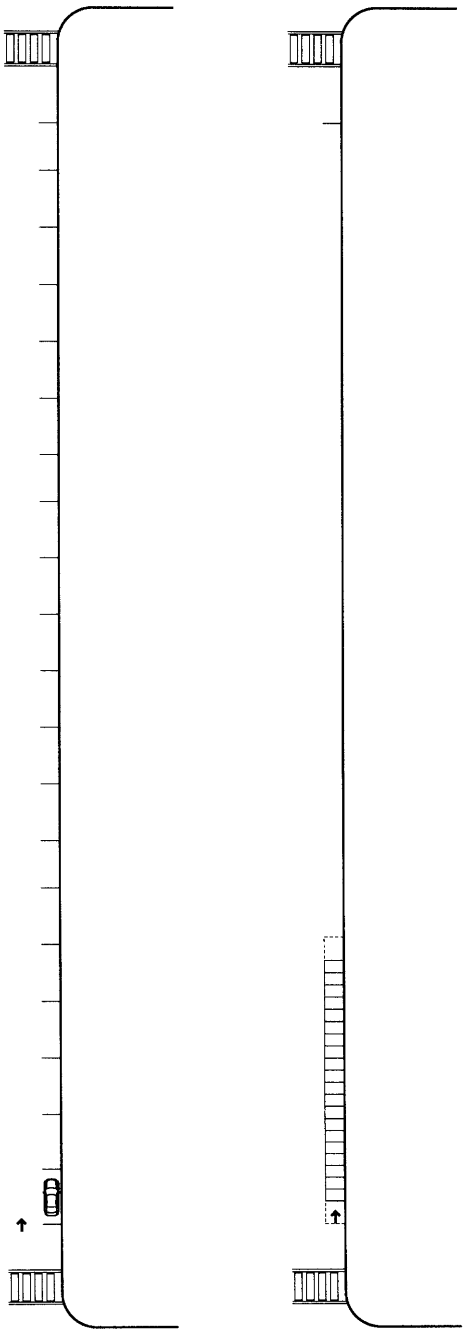
unit will confirm that there are no passengers inside the cabin, and that all doors have been shut. Only then, the car will start the process of shifting from driving position into parking position. Two hydraulic actuators working in combination with the robot wheels make this possible. The front wheels must be locked in place while the actuators lift the car up.
The bit car now begins to recharge its batteries while it waits to reach the front of the stack and a new user who will drive it again.

City cars and the physical network

The bit car is significantly different than any vehicles on the road today because their design is adapted to the conditions of urban travel.
The main adaptation that bit cars has to do with its physical properties and how they connect to the physical elements of the transportation network. There are many levels of efficiency combined into the system, and all of them are interrelated, but probably the most recognizable aspect is their space efficiency.

In a typical situation, bit cars can compress to a ratio of approximately 1:3.5 in a standard curbside parking arrangement. That is, three city cars fit in a regular parking stall of 8’6″ x 22″. In parallel parking, it is necessary 468 feet to accommodate 20 parking stalls, but bit cars require only 123 ft for the same number of cars. On-street parking takes less land area than other forms of parking because the ramps, driveways and aisles required in lots and garages are absorbed by the street travel lanes themselves. These numbers include the space required for maneuvering a car in both situations. For a conventional vehicle, it is necessary to leave enough room in front

Fig 10.4
On-street parking comparison



3744 sqft
20 vehicles
187.2 sqft / car
3.57 : 1

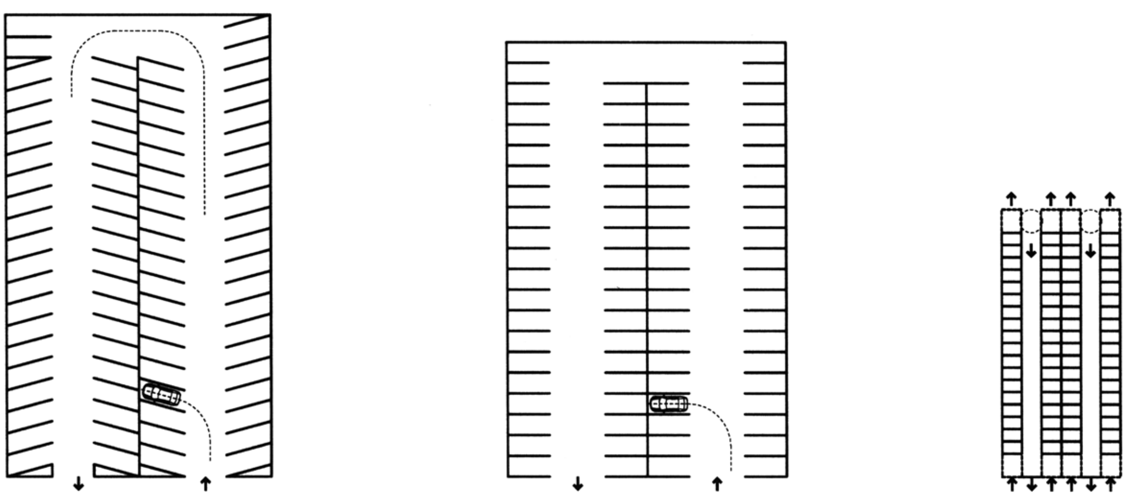
1047 sqft
20 citycars
52.35 sqft / car
1

and behind the car so it can enter and get out of the parking spot. For a bit car, on the other hand, it is necessary to leave enough room for one unit to be fully extended (in driving mode) at both ends of the stack, but the space per parked vehicle is reduced to 62 inches (1600mm).

Of course, CityCars can also park in other locations besides a car stack. But even then, the parking efficiency is also higher than for regular vehicles, thanks to the use of the robot wheels, which offer omnidirectional movement for the unit. This effectively allows CityCars to park in very tight spaces without awkward maneuvering, and eliminating the residual space. To better explain this feature, simply imagine if all standard automobiles would be equipped with wheels capable of rotating 90 degrees. This feature alone would be sufficient to decrease 5 feet of parking space per stall, from the 22' required for parallel parking to the 17' mandated by the "design car". It would be impossible to quantify the exact gains, because numerous small spaces that cannot currently be used for parking (for example between a bus stop and a fire hydrant) would open up.

The efficiency of stacking bit cars becomes even greater when compared to off-street parking layouts.
Stacks of bit cars favor linear situations, in which the entrance and the exit to the parking area are at opposite ends. However, if the

Fig 10.5
Bit car parking between conventional cars



22014 sqft
80 vehicles
275.15 sqft / car
3.83 : 1

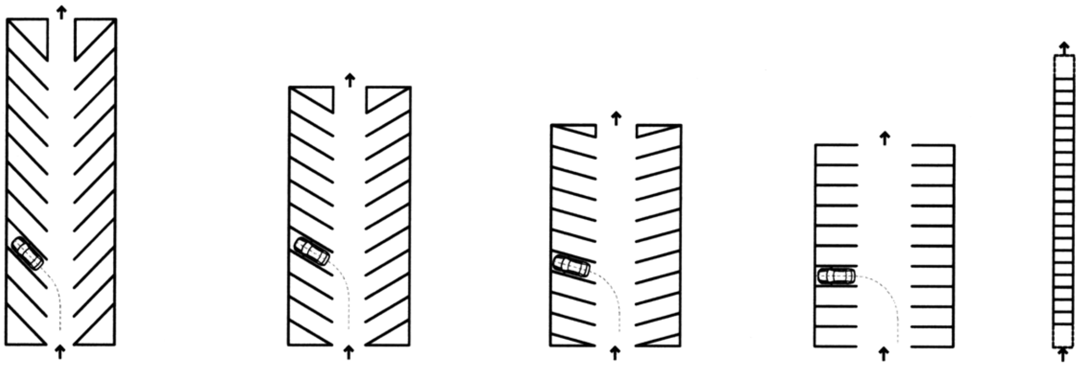
22050 sqft
80 vehicles
275.62 sqft / car
3.83: 1

5752 sqft
80 vehicles
71.9 sqft / car
1

Fig 10.6
Off-street parking layout comparison with access on one end

conditions force the entry and exit points to be on the same side, the layout for bit cars is still almost 4 times more efficient. This is in part thanks to the combination of its stacking capabilities and their zero turning radius, which eliminates the need for roomy alleys. Figure XX compares an equivalent arrangement for 80 cars with the condition of entry and exit on only side of the perimeter.

The space gains start piling up if the parking area has entry and exit points on opposite sides. Figure DD shows the area requirements for 20 vehicles parked in different layouts, based on the geometric properties described in chapter 4 (parking stall width, length, aisle dimensions, turning radius). Naturally, the dimensions of the lot available for parking would determine what the real gains are. But for example, for a relatively low number of vehicles (20), a scheme with cars parked at 90 degrees versus 20 bit cars yields a ratio of 1/4.87 (4.87 bit cars fit in the space of one standard car). The numbers go up when stalls are arranged at an angle: 1/5.01 for 75 degrees,



6526 sqft
20 vehicles
326.3 sq ft / car
1/6.23

5728 sqft
20 vehicles
286.4 sq ft / car
1/5.47

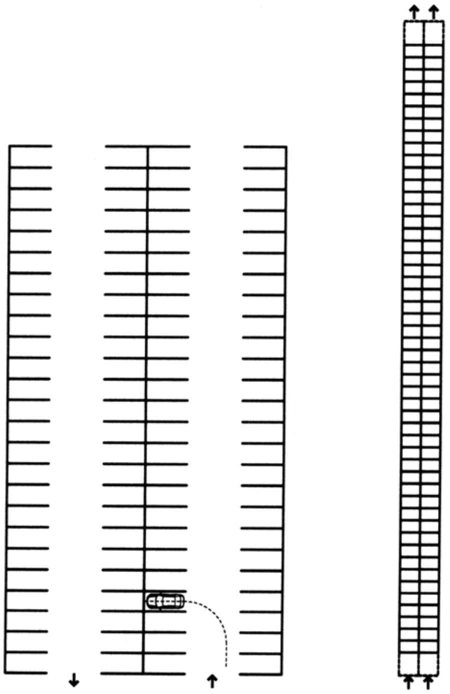
5247 sqft
20 vehicles
262.35 sq ft / car
1/5.01

5100 sqft
20 vehicles
255 sq ft / car
1/4.87

1047 sqft
20 citycars
52.35 sq ft / car
1

Fig 10.7 (above)
Off-street parking layout comparison with access on opposite ends

Fig 10.8 (below)
Garage parking layout



27000 sqft
100 vehicles
270 sqft / car
5.71 : 1

4728 sqft
100 vehicles
47.28 sqft / car
1

1/5.47 for 60 degrees and 1/6.23 for 45 degree parking.

Even for large number of vehicles, the space saving ratios are high. Figure JJ illustrates the raw foot print needed to accommodate 100 vehicles in what could be a parking garage, without taking into consideration ramps, structure and other elements that usually come into play. The use of bit cars can reduce up to 6 times the space requirements.

The efficiency of different parking layouts is a hot topic of discussion among engineers, but the reality is that design is always conditioned by a number of external constraints. Actual location, dimensions of the lot, orientation to access roads, finances, city regulations, etc. restrict the efficiency of the land, so it is not unusual to find parking lots with higher square footage per vehicle than in these generic diagrams. Figure WW shows one example. If the dimensions of the lot are 47 ft by 138 ft, and accessibility is restricted to only one of the long sides, it is only possible to accommodate up to 18 vehicles at a 45

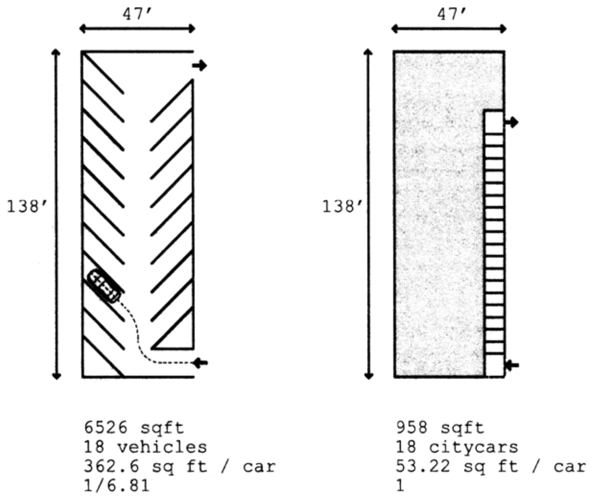


Fig 10.9

Off-street parking comparison with specific constraints (dimensions and access)

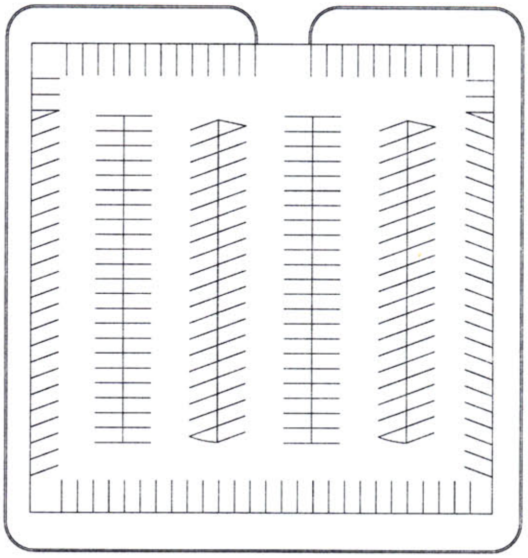
degree angle, and there would be some residual space that cannot be utilized. In contrast, 18 bit cars in the same situation would take just 1/7th the area.

It is true, however, that the comparison must take into account the fact that bit cars can only carry two persons, whereas a standard vehicle (one that fits in a regular parking stall) may carry up to 5 passengers. However, this comparison does not reflect the current use of private automobiles. As pointed out before, only around 4% of all trips are carried with 4 or more passengers in the vehicle. But in any case, it is important to re-iterate that bit cars do not replace all kinds of automobile travel, so it will still be necessary to account for a number parking spaces for other kinds vehicles and their specific spatial requirements.

The comparison, still, is not entirely fair, because bit cars are shared, and traditional automobiles are not. That means, that when a user leaves a bit car in a stack, and after it is fully charged, someone else will take it for a

spin again before the first user needs to use a bit car again. So in reality, bit cars, just like other car-sharing programs directly reduce the number of units necessary to mobilize a certain group of the population. The estimates on these gains vary greatly, claiming that one vehicle in a car-sharing program takes between 4 and 16 privately owned cars off the street. In fact, a study by the Transportation Research Board in 2005 concluded the number was close to 14.9 based on the situation of car-sharing programs at the time.
Even using the most conservative number, and estimating that each bit car also replaces 4 conventional cars, the space-saving gains can be stagering since they are multiplied four times. In other words, we can speculate that 20 people who currently drive their own automobiles may share the use of just 5 bit cars, and in turn, 5 bit cars will take the space of just one traditional automobile. That is a saving of 20:1. Assuming the data of the TRB is accurate, and each vehicle in a car-sharing program replaces an average of 14.9 privately owned cars, then the ratio jumps to 74.5:1.

In figure AA, I have taken one block from downtown Houston, TX, located between Main street, Bell street, Travis street and Clay street, which is currently devoted entirely as a surface parking lot. The block is 250 feet on each side, with a usable area of 62500 sq feet. Inside it, there are 260 stalls (with some very awkward spots), so each vehicle takes up about 240 sq feet, which is a very good efficiency rate for a parking layout.
With a full fleet of bit cars in Houston, this block could be entirely redesigned with bit cars in mind (figure AA.02) and almost entirely reused to create green spaces, skyscrapers, shopping or recreational areas or anything that urban planners and the



market can imagine. Four stacks, each with 17 bit have been moved next to the side streets (no need to store the vehicles deep inside the block), making a total of 68 bit cars, which would replace all the parking spaces in the original diagram. The entire block would regain 60,725 sq feet out of 62,500 sq feet (97% of the land) for other purposes than parking and still fulfill the spatial needs of storage of units for personal mobility.

In the particular case of Houston, TX, the problem is exacerbated because this block is not alone. In fact, it is surrounded by many blocks in similar conditions. So the utilization of bit cars as public transportation can have dramatic effects on the configuration of the city. Figure UU shows a diagram with all the open-space parking lots (it does not include multi-story parking garages) in the downtown area, which currently take approximately 21% of the surface. To put this in perspective, the Central Artery/Tunnel Project in Boston, MA (known as the "Big Dig") brought 00 m2

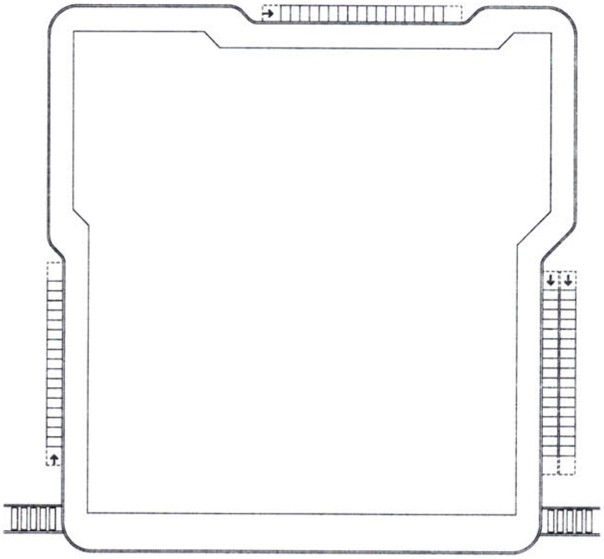


Fig 10.10
Sample block in Houston, TX destined for parking (above) and comparable arrangement with bit cars

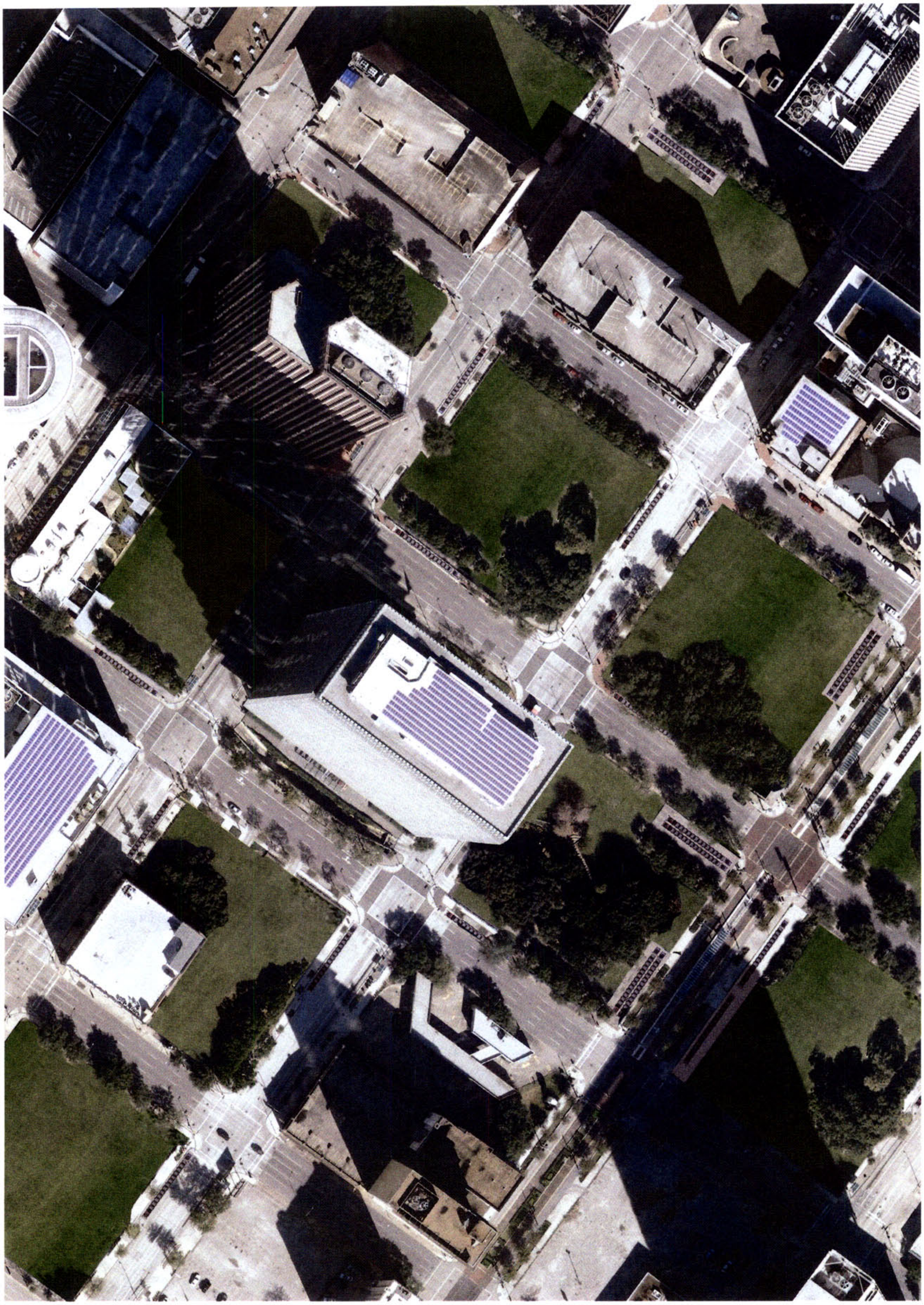
in usable land back to the city.

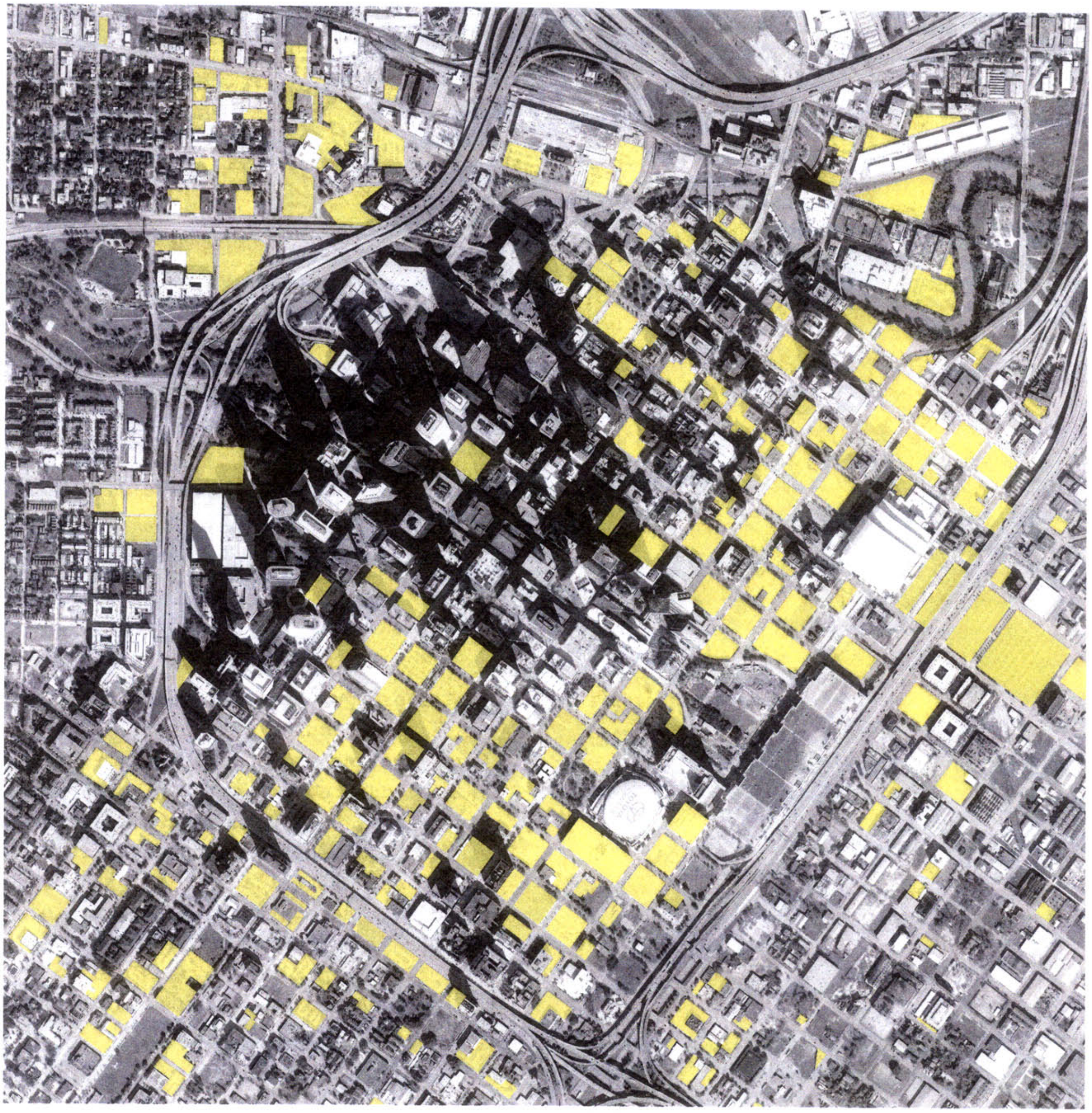
To better illustrate this transformation, Figures MM and NN show the "before and after". Figure MM is the actual condition, a desolated almost completely paved landscape, with considerable distances between the location where the driver leaves his/her car and the destination point (four or five blocks walks are not uncommon). When quantities are so large (number of cars, distances, etc.) there are many other problems that come associated with them. Everyone who drives and parks in similar conditions has experienced some level of difficulty in finding an available parking spot, or has been unable to find the exit, or has been lost and confused as to where he/she left the car parked.
Figure NN shows an entirely different image of the city. For illustration purposes I have only created green spaces to highlight the new areas that the city would gain but, needless to repeat, these spaces could be a combination of many different things (office buildings, housing, shopping, recreational areas, etc). Still, the distribution of bit cars represents the equivalent condition depicted in the original image. Some stacks have higher number of cars because they are closer to the light rail line (LRT), some stacks are placed next to the streets, and others off-street, to show different strategies. By no means, this is an exhaustive account, but just an exercise to demonstrate the possibilities at stake.

As seen, this scheme presents a clear opportunity for reshaping the landscape at the urban scale. But this is also a big impact in the human scale, and a shift in the way we experience the city and its architecture. Take, for instance, the outstanding Walt Disney Concert Hall in downtown Los Angeles,

Fig 10.11 (next page)
Downtown Houston, TX current configuration

Fig 10.12 (page after next)
Downtown Houston, TX possible configuration with bit cars





CA, designed by renowned architect Frank O. Gehry. If you are going to a concert, you can drive directly to the six-level underground parking garage with room for 2,188 vehicles. From there, you take the escalators straight to the foyer without ever stepping on a sidewalk. The exterior of the building that has become a new icon for the city -and ironically one of the most common backdrops for automobile commercials- can be

Fig 10.13

Open parking lots in downtown Houston, TX completely ignored.

In suburban areas and situations where the location does not justify underground parking, the reception to an office building is sometimes a huge parking lot. The residential complex where I live in Los Angeles has no pedestrian entry. One must drive into the resident's garage and take the elevator to the appropriate floor, and guests must do the same into a separate subterranean garage level.

These scenarios can radically change with a fleet of bit cars. Because the parking requirements are so small, and there is no need to locate one vehicle in particular, there is only one drop off point (where the car is then stacked) and one pick up point. The stack itself can be integrated with the building itself, and becomes nothing more than a 'technical' space where few people have access to. So you actually can drive directly to the entrance, leave the car at the drop off point and walk into the building, just as if you driving into a high-class hotel or restaurant. It is almost like having a valet service wherever you go: you drive up to your destination, leave the car at the drop off point and forget about it. When you come out, you head straight to the pick-up location and you do not even need to wait for the valet to retrieve your car: your bit car is already waiting for you.

Citycars and the transportation network

City cars offer several ways of integration with the existing transportation network of a city. It all depends on the specific characteristics of each city, and deployment needs to be carefully articulated to match its requirement.

As explained before, except in cities with an unusually extensive transit system (such as New York City), there is a gap between the transit stop and the passenger's final destination. City Cars can easily bridge that gap by pairing stacks of vehicles at the stops of transit networks, such as subway stations, bus terminals, and airports. Other locations for stacks are major origin and destination points in the city, such as hotels, apartment buildings, shopping malls, supermarkets, universities, hospitals and so on. This scheme for shared vehicles is known as multinodal. Most trips are done between these somewhat fixed points in the city grid. In essence, this is not different than any other transit system, like the bus or the subway, but it provides the additional benefit of being available on demand. That is, users can take a car right at the time when they need one, without having to wait for the service to come.

Another benefit is the flexibility of the network of city cars. Cities are constantly evolving. In a few years, entire business areas flourish and others disappear, while neighborhoods are created or renew their population, and often times it is difficult for transportation systems to adapt to these changes quickly. Unlike rail systems, for example, stacks of cars can be relocated with a minimal cost, and respond immediately to even small changes in the configuration of the urban fabric.

One key advantage of CityCars is their adaptability. To understand this concept, we must compare it with other systems. Mass transit is highly efficient in densely populated areas, but it would be too expensive and unsustainable to send a whole train every 10 minutes to transport a few passengers to the suburbs. Transit is too monolithic and unable to adapt to varying patterns of land use, which also shift over time. Proponents of public

Fig 10.14
Bit cars next to light rail transit in downtown Houston, TX

transit are always eager to indicate the high efficiency rates when compared to the private mobility, but these numbers are only true when the bus or the train is full. In most cities, this only happens twice a day, corresponding to the beginning and end of the workday. At non-peak hours, these systems become very expensive to maintain with the same frequency of service. In these cases, too, CityCars can further complement transit by covering the transportation needs at these hours.

On the other end of the spectrum, for the number of people they can carry, private automobiles require excessive parking space and stay idle for most of the time in downtown areas where land is most valuable.

City cars, again, would have a spot in between the transit system that cannot take one passenger to the suburbs and the vehicle that cannot take too many people downtown. In areas of lower density, the system can move around just one person thanks to its ability of dispersing small individual units, and in areas of higher density, they are capable of compressing the parking requirements thus freeing up space where its most needed. Adaptability is the result of a simple collapsible design, not unlike a pocket knife serves its purpose of cutting objects and then is folded away to be stored safely inside a pocket. The folding and stacking provides two levels of adaptability, because not only the unit is capable of reducing its own footprint, but they also act as a larger entity when they form a stack.

Other interesting settings are growing cities and those without an important transit network or an outdated system. Development of heavy rail lines require a massive investment and many years of planning and construction, especially in already developed cities with high density of population (example?). On the other hand, younger, smaller urban nodes typically have lower gross income and cannot afford the cost of developing a subway network or another rail system. In many of these cases, it is expected that most of the transportation needs be met by the automobile.

In cities which already have a network of buses, subway lines and other systems, city cars complement the existing infrastructure by extending its reach. In cases where the infrastructure is under development, the presence of vehicle stacks may also have a strong impact on the design of the transportation grid, by differentiating them even more. Thus, mass transit could run on faster lines, with fewer stops in between. Instead of just covering the "last mile" gap between the transit stop and the destination point, city cars could do the job of the "last two miles". This could potentially benefit bus networks as well, since one of their main difficulties of their service is running on schedule, partly due to the number of stops they have.

However, one of the most compelling scenarios is probably among the most radical ones. While one can clearly see the logic behind locating car stacks in popular destination points, ideally, city cars would be able to park and stack ubiquitously throughout the city. That is, every block of the city, every corner could potentially become a parking stack. This virtually eliminates the concept of a "stop" in a transportation grid. Anywhere you want to go within the city is fair game, and the maximum distance to your actual destination is, in fact, only a few steps away. This also supports the idea that parking stacks, which need also be recharging stations, must come in different versions, with at least one design simple enough to be easily deployed in every corner where parking is possible and electricity is available. A system like that would be the equivalent as having a service station to refuel your car in every corner with one notable advantage: you never actually make the trip to refuel your car, you drive to your where you want to go and the refueling is an added bonus.

In a way, Citycars are similar to taxi cabs: they are available to the public, and they offer personal mobility on demand exactly from the origin point to the precise destination. Stacks of citycars would be the equivalent to taxi cabs stops. Besides the differences in the vehicle itself, the service offered by taxis includes a chauffeur, who not only drives the car but also provides orientation and negotiates the information between the physical network and the passenger. The taxi cab driver knows -at least ideally- which is the fastest route and which is the shortest way to get to the destination. Because of this, the service can be expensive, and is always subject to the skills of another driver. On the other hand, users in a citycar must drive the vehicle themselves, making it substantially more affordable; and the knowledge of the cabbie is replaced by onboard computers which provide the driver with all the relevant information to navigate through the city streets.

Citycars are an advanced implementation of car-sharing. The principle is the same, with the added benefits of using a vehicle specifically designed for this purpose. Unlike current car-sharing companies which use conventional automobiles, Citycars are more convenient because you do not have to return the car to the origin of the trip. A one-way rental system has a two-fold benefit. First, there is the potential of increasing the shared use of each car because units are released back to the public once they arrived at another stack. That means the cost of running the system is distributed over a larger pool of people, thus reducing the actual price tag by hour of usage. Secondly, each user only pays for the actual usage of the car. Current car-sharing implementations like Zipcar must charge for the entire time of the reservation, regardless of whether the car has been used all the reserved time or not. In fact, in most cases, cars still spend most of the time parked, locked, away from their origin point. For instance, a member who needs to go shopping for groceries, rents a car for two hours, drives 15 minutes to the store, parks at the convenience store for 1 hour and 20 minutes (maybe even pay for parking) and drives 15 minutes back to return the car 10 minutes in advance to avoid a late fee. If the car needs refueling, the time spent at the

gas station is also included in your bill.
Users or Citycars are only billed by the actual usage of the car on the road. Once you return the car to the back of another stack, in some other location, it becomes avaliable to anyone else and you do not have to worry about refueling.

Citycars and the information network

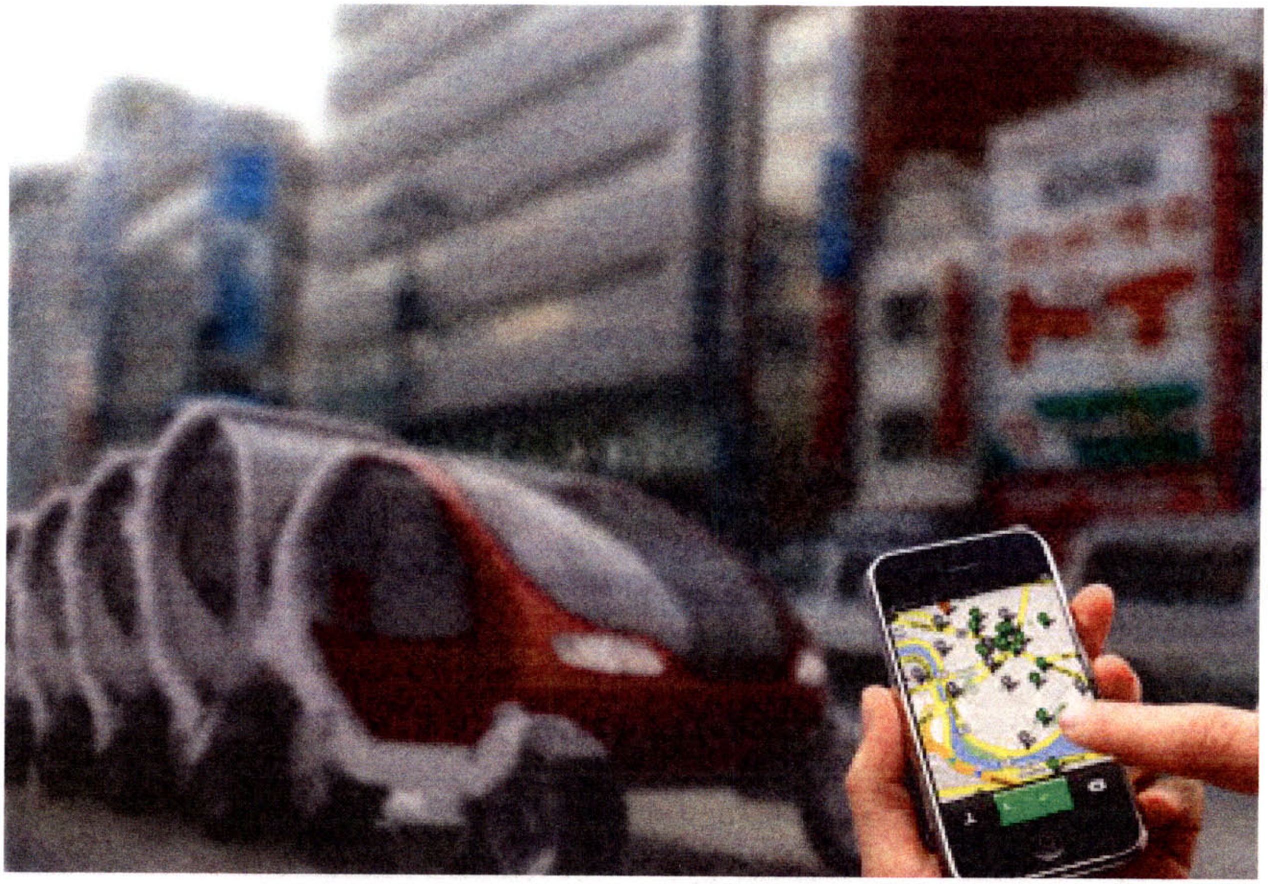
As discussed before, the distribution of Citycars on the urban fabric can have different levels depending on the particular situation. In dense areas, stacks could be located continously every few blocks just like bike sharing systems, and in other cases, they could be located in direct relationship to transit stops. In any case, the system would also feature location-aware devices, which will further reduce the latencies. All vehicles would be equipped with GPS, so that the management has real-time information on the distribution and movement patterns of city cars. Additionally, this information can then be extended to the users. A user with a handheld information device, such as a cellular phone or similar is then able to know which is the closest stack with cars, fully charged and available to drive. Car-sharing has already been greatly enhanced by the use of so-called intelligent transportation technology (Barth, Todd, Shaheen 2003). The use of technology has improved the overall efficiency, user accessibility and operational manageability. These systems manage availability and reservations over the internet, the telephone, automated kiosks, etc. Smart cards, RFID and similar technologies assist with vehicle access control, and location-aware devices allow tracking of the fleet at any time, for overall control, emergencies and electronic pricing.

While these technologies can provide benefits to private automobiles, they are a crucial component for shared-used schemes, because they can greatly assist in the managing the resulting overlap of demand and distributing the necessary supply over an adequate window of time and space.

Because of our cultural patterns, one-way car rental presents the challenge of correcting the distribution of units. Most people go to work and leave for home at the roughly same time, and want to enjoy their free time with other people. This can easily translate in a disproportionate distribution of citycars in certain locations at certain times, and some congestion seems unavoidable. However, this is not a unique case and important lessons can be taken from other fleet management systems, such as air travel. More

Fig 10.15

Access to stack information through the use of cellular phone



importantly, the use of real-time information through wireless networks can be used to tackle this problem. Citycars equipped with GPS devices enable drivers for a more efficient navigation through the physical network, but it also provides the management with information about the fleet movement, traffic speeds, stack availability, etc. All this information can be converted into a supply-demand organizational system. With a scheme of flexible pricing, the management can then control the demand and thus regulate the self distribution of vehicles. Thus, trips to congested areas with short supply of available stacking locations will feature a higher price than trips to other destinations. This information is then transmitted immediately to the communication device in the vehicle and to the driver who sees different the pricing of the trip according to the final stacking location (map). Real-time pricing information can also be available to other users and citizens in general through the use of personal handheld devices. Smart phones and PMAs that are wirelessly connected and equipped with location-aware systems (GPS) allow for sophisticated trip planning, which in turn facilitates the application of dynamic pricing schemes. Users can easily see the availability of citycars and compare prices among pickup and drop off stacks and choose the best combination based on their need and budget.

For bike-sharing systems, the management commonly utilizes trucks or vans to redistribute the units when certain racks are emptied and others overcrowded. Naturally, this represents a cost that must be covered in the price of renting the bicycle. Thanks to the compact design of citycars, similar approaches may also be employed to move cars around. Certain moving companies use lightweight trucks that can maneuver in most city streets to carry several small pods or containers. These pods are distributed to customers throughout the city and picked up later to be moved to their final destination in larger freight trucks. This method could be used to relocate citycars, especially at night when traffic is considerably slow. (image).

Another alternative would be to include citycars with virtual-towing capabilities and form small train-like chains of units that simply follow the car in front. This would be effectively the same as moving an entire stack or a portion of it from one location to another in higher demand for vehicles. As explained before, Citycars would already be equipped with a similar feature for automatic organization in the stack and prevent the stack from progressively moving backwards. This is a very interesting possibility because it is capable of offsetting large differences with minimal utilization of human resources (ie. one person driving the front car can move several cars at once).

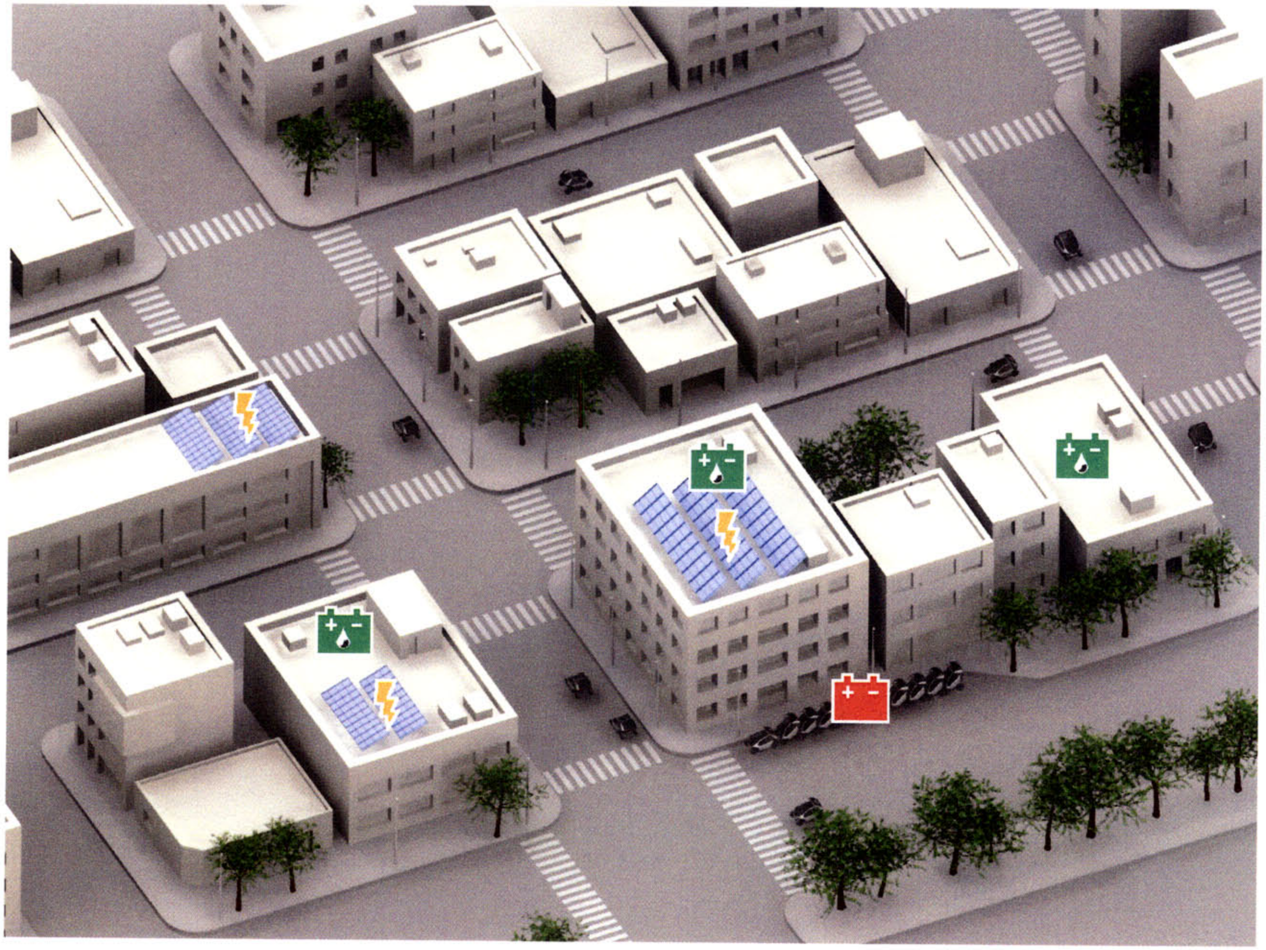
An interesting option is to extend the pricing incentives to segments of the population that do not necessarily follow the schedules and travel patterns of the majority. For example, a system of credit or cash-back can encourage students and unemployed people in the city to make the trips that are in lowest demand, rebalancing the system to anticipate near-future demand.

When none of these options are able to be implemented, combinations with transit and paratransit systems in the city offer further possibilities for fixing an imbalance in the distribution of citicars. For example, a van carrying a small crew of employees can be deployed to move cars from one or several stack location to another.

Citycars as collectors of information about the city. they can easily update the status of streets, congestion, accidents, pollution, driving times, necessary repairs, status of parking (stacks or not)

Citicars and the energy network

Energy is one of the most debated subjects of our time, and a detailed analysis escapes the purpose of this proposal. However, we must mention some of the implications of this proposal at least in a very general way.
Althought the actual configuration of Citycars may vary according in its implementation, the potential to embrace energy-efficient technologies is there. As stated before, a lightweight vehicle requires less energy be moved, the use of in-wheel electric motors is more efficient than internal combustion



engines and eliminates transmission losses of conventional drivetrain configurations, so there are multiple opportunities for engergy savings.

A large feel of electric vehicles can also provide interesting combinations with the electric grid of the city. Citycar stacks may be directly combined with clean, renewable energy sources directly attached to the stack charging infrastructure or to buildings nearby. Building rooftops could be outfitted with solar panels or silent wind turbines to capture energy as mentioned in chapter 9. Large number of citycars, in turn, can offer significant battery capacity on to the electric grid, and when cars are not in motion, this energy can be made available back to the city. Fuel cells maybe embedded in buildings as well, and create a distributed energy network with multiple sources and reduced transmission losses. Although this is a somewhat simplistic scenario, the possiblities for new kinds of energy combinations are indeed there, and opens up the opportunity for further research and development in many fronts.

conclusions

This work presents one scheme and a few alternatives from the design process, but it must be mentioned that different versions of the vehicle, the collapsible system and the stack based on the same concepts are necessary and encouraged. This design is not a one-fits-all solution, as cities have evolved differently and create distinct requirements. For example, low-density urban areas such as Los Angeles are characterized for longer distances in the average trip, so the design of a citycar may require a greater range and thus a bigger battery. Another constant in my design process has been to maximize transparent surfaces. However, in cities like Sydney, it might be necessary to provide additional sunlight protection. These are just examples and there are many design possibilities open as a continuation of this project.

We do not think there are significant hurdles in the implementation of a project like the CityCar. In terms of technology, almost everything seems feasible. Perhaps the weakest point is still the battery technology, because it presents some challenges in terms of battery cycles, and re-use or disposal of the chemicals in them. However, scientific development in this area is

also advancing rapidly and we should expect to see new technologies in the near future. Probably the weakest, unresolved issue to date is a convincing method for recharging these batteries. This method must be fully automated for the system to work efficiently. Plug-in methods may recharge batteries relatively quickly, but if they are manually operated, a mishap could result in large number of unusable units. Induction systems, on the other hand, would seem ideal since there is no user involvement required, but they are not nearly as efficient or fast, and a more costly implementation.
In any case, these issues should be resolved with a scientific research and a little creativity.

The work presented here also suggests that there could be different variations in the design for short term implementation. The design of the vehicle is not restricted to electric vehicles, and some important benefits could still be achieved with hybrid or other kinds of propulsion methods.

Perhaphs, one of the most important aspects this work brings up is the need to address the problem of urban mobility from many different aspects. So far, urban designers, policy makers and car manufacturers have been working independently of each other, but a project like this would require an interdisciplinary team for actual implementation.

Besides these issues, perhaps the only real obstacle to adopt such a system has to do with the cultural significance of the automobile. For over 100 years, we have come to assume that cars are private property, and they carry meaning besides their functional role. Citycars go against this notion, and it would require a cultural shift to accept that cars may also work as common goods, just like a bus or a train. I have deliberately chosen to ignore these aspects when developing this project, but they still exist and could become a decisive factor for success.

However, the potential is there. A new approach to urban mobility could have huge consequences in the shape of our cities and in the way we live in them. The staggering savings in land space have the potential to reshape entire cities, especially those with high automobile-dependency and huge areas destined to parking lots, by bringing massive portions of real estate in prime locations back to the city and their people. But this is also crucial for cities in formation and cities in China, India, Latin America and other developing countries, that have not yet adopted the private automobile in the same proportion, and are still in time to create more sustainable environments for future generations.

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