OENG1118: Sustainable Engineering Practice and Design

Design Deliverable

Group number 7

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Executive summary

The report details the application of sustainability principles and skills to car parking facilities in densely populated areas. The key subsystems explored were Transport, Structural, Hardware Systems, and Software Systems. Opportunities were identified in each of the subsystems, leading to a cohesive direction in which further research can be carried out. Throughout the investigation, the team has identified improvements that can be carried out to each identified subsystem along with theoretical targets that objectify its aim. The team believes that reductions of materials consumption are possible through recycling and salvage of structural materials, and the positive enhancement of its effect towards the ecosystem surrounding the car park. Transport system will prioritized customer's safety and convenience through appropriate/safe layouts, dimensions and alignments to be applied on lanes and parking spots. Finally, the integration of hardware and software systems that allows for faster, secure and convenient access, as it aims to reduce the amount of hardwares (removing the ticketing machine, and reducing gate systems), and maximise long term advertisement and economic advantages for both parties (e.g. car park's organization and customers).

Glossary

Vehicle - A machine that transports people or cargo. Therefore includes cars, buses, bicycles, trains, etc.

Ferrosilicon - Iron and silicon metal alloy.

Transport - The facilitation of movement for vehicles and people within the facilities, which incorporate layout and design (not transport's structure/mechanical systems).

Structural - The static structure for supporting the above transport of people and vehicles. This includes the foundations, supporting walls, floors, beams, columns, etc. This does not include mechanical systems.

Hardware Systems - The physical aspects of the control system that works together with software systems to enhance client's experiences with efficient hardwares and energy usage (e.g. boom gates, signalling lights, sensors, data and control wiring, cameras, on-site controllers, etc.)

Software Systems - The virtual systems that provide a customer interface via the internet, and manage the allocation and pricing of the facility. There is a strong integration between software and hardware systems.

1 Introduction

Transport enables almost all aspects of human interaction, whether it be by foot, public transport, or private vehicle. Freedom of movement is such an integral part of human communities and societies that the need for it is protected in numerous constitutions, including by Article 12 of the International Covenant on Civil and Political Rights (ICCPR) (Australian Human Rights Commission 2021) .

In Australia, even in a densely populated zone such as Greater Melbourne, a study in 2016 showed that 60% of workers used cars (as drivers) to transit to work (Informed Decisions 2016). There are obviously other uses for car parks such as tourism, business travel, and recreational activities. The continued popularity of private transport has obviously enabled the prevalence of car parking facilities, in Melbourne CBD alone there are 140 commercial car parking facilities, and 3000 marked bays on streets (City of Melbourne 2021).

Despite their widespread presence and utilisation, car parks have a reputation for being an unpleasant experience, both in terms of quality (typically dirty, smelly, potentially unsafe, poorly lit places) and value (often with complicated pricing models which lead parkers into unexpected charges).

The importance of car parks, combined with the poor quality service currently offered, presents an opportunity to explore improvement and redesign opportunities, which is the purpose of this project.

2 Product/service

Passenger transport as a whole is a broad and complex topic, and as such the more specific topic of temporary storage of vehicles in high density areas has been chosen. This is most commonly seen as parking and this will form a key part of our discussion, but will include the entire customer experience as they make transportation choices, interact with the service (both before, during and after physically using it). We will consider parking facilities, along with street parking, in both CBD locations and high density suburban areas (such as universities, hospitals, and shopping centres). The key subsystems that will be explored are Transport, Structural, Hardware Systems, and Software Systems.

3 Engineering design for sustainability

3.1 Sustainable development and regenerative development

Based on the aforementioned subsystems, multiple approaches/methods have been identified to enhance each subsystem to be more sustainable.

Firstly, in this project, it is considered that the transport system will include lifts for drivers to go in and out. Furthermore, parking access of the disabled will be planted close to the lifts, typically on the first floor and will utilize ramps for wheelchairs. To provide safety conditions, unobstructed visibility and separated walkway from carriageway are required as mixed movement of cars and pedestrians is hazardous (e.g. injuries and property damage, etc.). Parking space and line sizes will be set based on Australian standards.

Secondly, structural components of the car park can be enhanced by maximising the use of recycled materials. On the other hand, it is important to ensure that the used materials can be scavenged at the end of its life cycle. Furthermore, this approach provides opportunities for minimum energy usage in material manufacturing and installation. To achieve such opportunities, an adequate design is required to extend the used material's life cycle which reduces further waste.

Thirdly, hardware systems aim to utilize an efficient amount of hardwares while maximising qualities of the car park control system's infrastructure (applied logic/algorithm embedded in hardwares) and network for faster data communication with software systems. Hence, enhancing customer's experience. Essentially, it improves long term advertisement and economic advantages.

Finally, the software systems will be enhanced to reduce physical hardwares for authentication hardwares for entering, parking and exiting (e.g. ticketing machines and boom gate). On the other hand, it raises the potential to reduce traffic outside and inside the car park. In allowing customers to reserve parking spots with a mobile app, it provides faster car park access and improves long term economic opportunities for both car park and customers.

3.2 Design requirements and performance indicators

Subsystems	Design Requirements		Performance Indicators
	Customer	*Sustainability*	
Transport	Carriageway and parking spaces as per Australian Standards	Using ramps to reduce the cost	Capacity, how many cars go in and out at the same time
	Safety requirements	About visibility should look safe	Less minor accident records (e.g car body collides with wall).
		Include instructions pedestrians and people with disabilities	Proximity of disabled car spaces to elevators
Structural	Structural integrity as per Australian Standards	Using recycled material	Cost per metre squared / cost per car park
	Architectural requirements	Materials used that can be recycled	Life cycle
			Percentage of recycled material used
			Percentage of material that can be recycled
Hardware Systems	Strong signal for underground car park	Efficient performance on power usage, advertisement, hazard and real time data communication.	Customer reviews.
	Fast car park entrance authentication process	Guide drivers with unfamiliarity with the car park system as fast and easy as possible.	Minimum long term hardware maintenance cost.
			Number of entrances per day.
			Energy (electricity) consumed
Software Systems	Allow customers to use, plan and manage their parking, anytime, anywhere.	Optimise utilisation (less land required, more profitable)	Customer accessibility to website
		Reduced queuing (saving pollution)	Facility utilisation

Table 1. Design requirements and performance indicators from each subsystems

3.3 Theoretical targets for the design requirements

Subsystems	Theoretical Targets
Transport	No load during peak hours (about 8:00am, and 5:30pm)
	Approximately 1274000 cars (as drivers) are involved in traffic and 70000 car parking spots in Melbourne city (Craig and Timna 2017).
	No safety or property damage incidents.
	Distance from disabled car space to lift: 2m
Structural	80% material reusability
	50% material used from recycled sources
Hardware Systems	$P(Watt) = VI = \frac{E}{t}\,(Joule/day)$ formula for future development and managing energy usage per day.
	Implement binary search algorithm to find and check for existing parking reservation order, where the worst and best case time complexity is $O(log(n))$, and$O(1)$ (Imms 2021). As n is the number of reservation orders data.
	Utilize/implements PLC controller with ladder logic implementation for light, HMI and sensor that utilize 24V DC power supply (Gandhi 2020).
	DC power is converted from 120V - 240V line voltage (AC) of the car park (Cope 2018).
	Implement LTE signal booster typically $700 - 2600\ MHz$such as Telstra's $850\ MHz$ 3G/4G LTE booster.
Software Systems	100% booking conversion
	100% physical utilisation. Or allowing a 2 minute duration between slot changeover, for an average 4 hour booking, approximately 99%.

Table 2. Theoretical targets of each subsystem.

3.4 Frugal subsystems and processes

3.4.1 Hardware Systems

In order to create/demonstrate a frugal car park hardware system, some essential and non-essential considerations are generated.

3.4.1.1 Essentials

Firstly, sensors that detect movements will be utilized to manage light energy usage on the car park, which turns the lights on if and only if it detects movement of a large object.

Secondly, to reduce the amount of hardwares, strengthen the communication between IT systems to be implemented on electronic hardwares (e.g. camera, gates, and sensors) with the software system. Sensors detect and count the number used parking spots where the data will be sent real time records of the remaining available spaces to the software systems. On the other hand, incorporating camera and image processing to scan car plate numbers will simplify the entrance process to the car park, where the ticketing system is fulfilled through a software system.

Finally, conduct experiments and simulations that utilize maps of existing car park levels. The experiment will involve data sensors such as 2Hz and 50Hz OBD2 on a vehicle to find locations within the map that have the strongest and the weakest LTE received signal strength (RSS) level (Shin et.al 2021). Hence, the experiment aimed to generate/predict the optimal required number of 4G booster devices and its alignments/positions.

3.4.1.2 Non-Essentials

Some non-essential hardware can be in the form of LCD that will show the number of parking spots left, shows welcome messages and a guidance for drivers to wait for the camera to authenticate the plate number.

3.4.2 Software Systems

The customer interface can be designed in a frugal way, to meet their needs, as has been the trend of many highly successful applications (eg. Uber, Google, Whatsapp, etc.). The pricing model can remain hidden, and provide the metrics required for the user to make a decision. The customer inputs will be a location and timeframe they wish to park. The application can perform analysis and present the user with intuitive visuals that assist their decisions.

Some customers may be less price sensitive, and prefer the simplicity of a pre-established account, meaning they can park anywhere, and only be charged for the time they use. Others may be more frugal and wish to plan ahead to unlock discounts, or even alter their plan timing, or means of transport, to optimise for cost.

3.5 Eco-efficiency

3.5.1 Structural

Car Parks are conventionally built primarily using reinforced concrete which includes aggregate, cement and steel reinforcement. These materials can be reused when the carpark building is being decommissioned and demolished at the end of its life cycle.

Crushed concrete is often transported to waste facilities where the concrete is crushed and used as an aggregate, this aggregate can be used to construct future structures and again scavenged at the end of the products life cycle.

Cement, a material used in concrete, can also be recycled from processes that produce byproducts, that would otherwise serve no purpose. Fly ash (ashcrete) a byproduct of coal powered plants can be used to replace cement, reducing the pollution generated from coal powered plants and reducing material cost. Blast-furnace slag, a byproduct of blast furnaces can also replace up to 70-80% of conventional cement products in a concrete mixture. Micro silica is a by-product of ferrosilicon alloy and silicon production, from the condensation of Silicon dioxide can also displace around 7% - 12% of cement in concrete. (Eco-Friendly Alternatives To Traditional Concrete 2019)

Albeit, improved eco-efficiency of reinforced concrete structures by utilizing recycled materials, studies shown in (University of Southern Queensland Faculty of Engineering and Surveying 2004) emphasise the reduction in load bearing capacity of concrete with higher percentage in recycled materials. It is crucial that material consistency and load bearing capacity of reinforced concrete be conserved in reference to load bearing structures, hence, green concrete should be used primarily in structures that will not be load bearing such as walk-ways and balustrades.

Steel can be taken as scrap and reused and unlike structural steel, reinforced steel is often recycled itself from steel scrap. Reinforce steel itself can then be recycled at the end of its lifecycle.

3.6 Eco-effectiveness

3.6.1 Structural

Many eco-effective ideas can be implemented in the structural aspects of a car parking facility. For example the design of a permanent structure with flexible use due to a non-prescriptive internal design (large open area). Using dynamically assigned parking bays through use of projected line markings allows for more flexible and future proof usage, which makes the most of the technical nutrients used.

The exterior of the facility presents opportunities such as vertical gardens on the surfaces of the garage, which improves both aesthetics. Trees and plants could also be integrated into the design to provide improved biological impact, potentially reaching a point to counteract the emissions produced by vehicles within (calculation needed). Natural convection may be used to increase ventilation on top floors of the structure (subject to HVAC engineering design), this is utilising the natural force of gravity to promote circulation of warm and cool air.

Making available bicycle parking has a fantastic social impact, encouraging uptake of the biological energy for transport, instead of fossil fuel. To further this, solar panels could be added to certain faces of the building, and the roof, which could be used to recharge electric vehicles, and power lighting (in place of traditional grid energy).

Utilisation of plant based materials like timber structures and signage was considered but may pose a safety hazard due to fire risks.

3.6.2 Transport

Regenerative elevator system was considered, but rejected because the traffic congestion would significantly limit car park efficiency due to queuing. Average speed of vehicle elevators is 0.5 m/s (minimum shipping time of 1 car is 20 seconds, maximum around 50 seconds). During the peak time cars will stack outside and inside. It wastes time, increases inconvenience. High maintenance costs in the case when the elevator breaks (Average cost of elevators 15000USD for vehicles and 8800-12000USD for pedestrians), and cause safety issues with pedestrians potentially trapped in the elevator.

3.7 Leverage points using whole system thinking

(currently 36 words)

A good opportunity to leverage whole system thinking is the hardware and software subsystems, as they are involved throughout the entire customer experience of the car park.

The three figures below outline this process as follows:

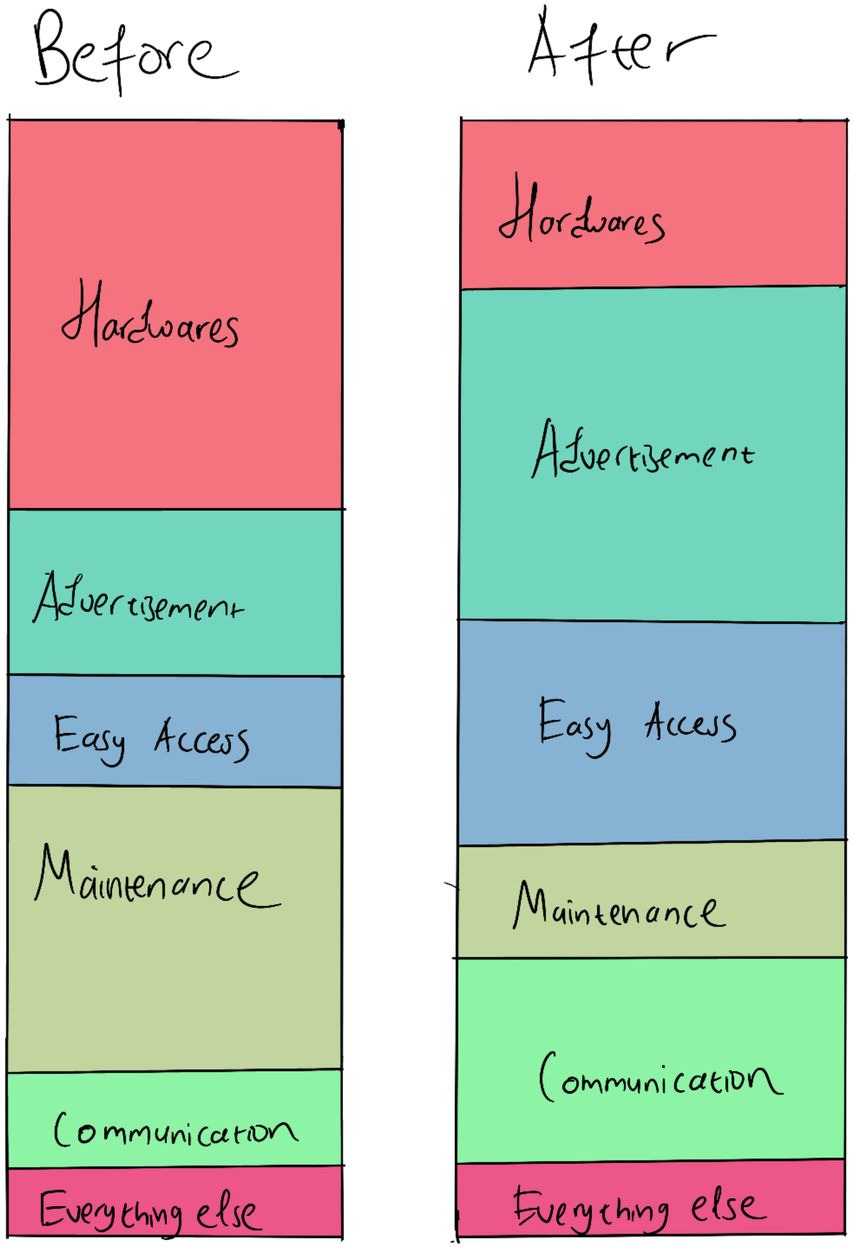

Figure 1. the conceptual benefits expected by application of this principle.

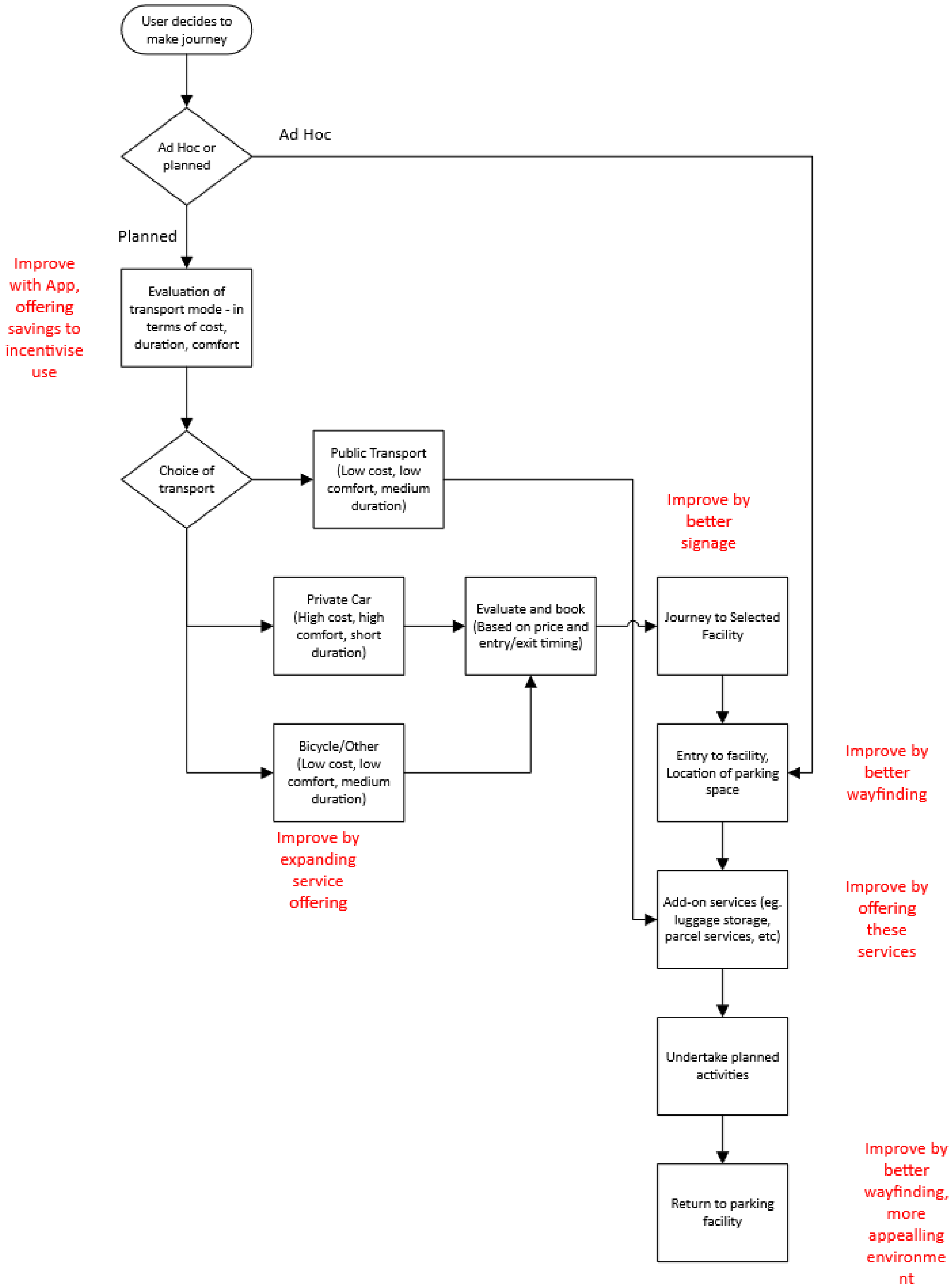

Figure 2. the overall customer experience, and some specific leverage points, many of which are outlined in this report

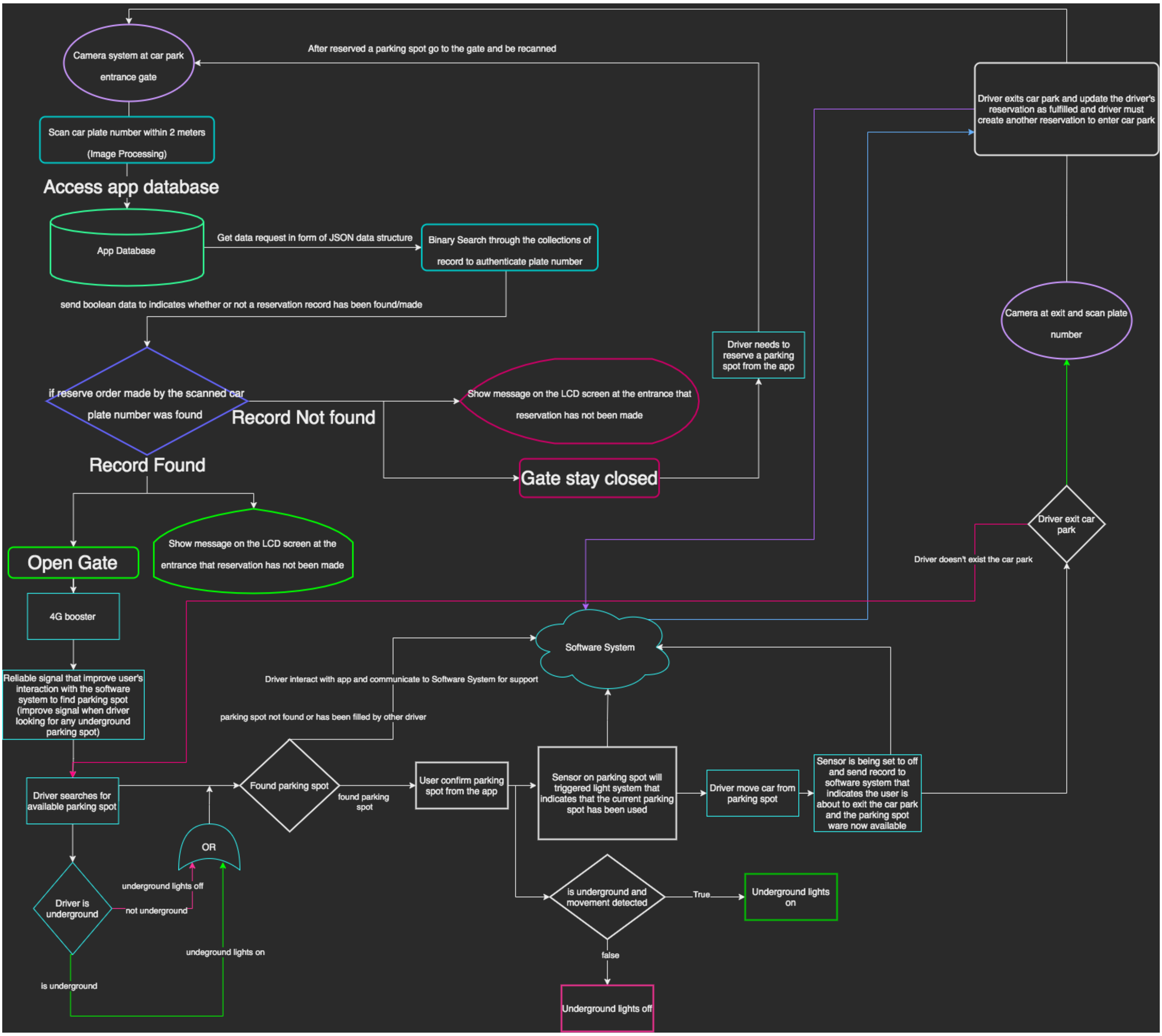

Figure 3. Image processing, authentication, controller and network systems (software and hardware interactions).

3.8 Optimal design sequence

3.8.1 Structural

Project planning as part of a council planning and building permit will require an architect / building designer to determine and document the structures shape, materials for most non load bearing members, layout and facade appearance. The carpark's design sequence will be completely optimised and determined at its planning and design stage where architects, engineers in conjunction with local council will negotiate and determine optimal design decisions.

Sustainable design decisions after a certain energy rating for a structure will be completely dependent on the architect/clients volition and these engineering design phenomena must be coordinated with an architect and client for approval.

3.8.2 Hardware Systems

People before hardware would be the appropriate design sequence for this subsystem. By designing a sustainable use of logic and its implementation to sufficient amounts of hardwares will raise cost efficiency (less hardwares, and long maintenance interval). On the other hand, strong communication between hardware and software systems will simplify driver's interaction/access to enter, park, and exit (improve client's experiences). Essentially the hardware system would want to maximise customer's experiences, improve advertisement and generate competitive advantages in long term period.

4 Conclusion

(currently 139 words)

In conclusion, the team aims for an efficient, economically and environmentally friendly car park, while the implementation proposed to each main subsystem, in the discussion above, would improve advertisement, social and competitive advantages.

Structural systems aimed to reduce materials consumption through recycling and salvage of structural materials, while improving its impact to the surrounding environment. With appropriate/safe layouts, dimensions and alignments to be applied on lanes and parking spots, the transport system will ensure customer's safety and convenience within the car park. Finally, hardware and software systems provide faster, secure and convenient access, while aiming to reduce the amount of hardwares, and maximise operational system control/logic, long term economic and advertisement advantages.

Further research and data collection would be required to support and enhance the current proposed development to be more realistic, convincing, and improve current implementations.

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