



**HAL**  
open science

# Privacy Laws and Privacy by Design Schemes for the Internet of Things: A Developer's Perspective

Atheer Aljerais, Masoud Barati, Omer Rana, Charith Perera

## ► To cite this version:

Atheer Aljerais, Masoud Barati, Omer Rana, Charith Perera. Privacy Laws and Privacy by Design Schemes for the Internet of Things: A Developer's Perspective. 2020. hal-02567959v2

**HAL Id: hal-02567959**

**<https://hal.science/hal-02567959v2>**

Preprint submitted on 14 May 2020 (v2), last revised 6 Aug 2020 (v3)

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# A Systematic Analysis of Privacy Laws and Privacy by Design Schemes for the Internet of Things: A Developer's Perspective

ATHEER ALJERAISY, Cardiff University, UK

OMER RANA, Cardiff University, UK

CHARITH PERERA, Cardiff University, UK

Internet of Things (IoT) applications have the potential to derive sensitive information about individuals. Therefore, developers must exercise due diligence to make sure that data are managed according to the privacy regulations of data protection laws. However, doing so can be a difficult and challenging task. Recent research has revealed that developers typically face difficulties when complying with regulations. One key reason is that, at times, regulations are vague and it is difficult to extract and enact such legal requirements. There is, moreover, a lack of practical guidance that considers the technical domain for developers to build a privacy-aware IoT application. For this paper, we have conducted a systematic analysis of the data protection laws that are used across different continents, namely: (i) General Data Protection Regulations (GDPR), (ii) the Personal Information Protection and Electronic Documents Act (PIPEDA), (iii) the California Consumer Privacy Act (CCPA), (iv) Australian Privacy Principles (APPs), and (v) New Zealand's Privacy Act 1993. Then, we used framework analysis method to attain a comprehensive view of different data protection laws and highlighted the disparities, in order to assist developers in adhering to the regulations across different regions, along with creating a Combined Privacy Law Framework (CPLF). After that, the key principles and individuals' rights of the CPLF were mapped with Privacy by Design (PbD) schemes (e.g., privacy principles, strategies, guidelines, and patterns) developed previously by different researchers in order to investigate the gaps in existing schemes. Subsequently, we have demonstrated how to apply and map privacy patterns to IoT architectures at the design stage, and have also highlighted the complexity of doing such mapping. Finally, we have identified the major challenges that should be resolved and potential research directions in order to take the burden off software developers when applying privacy-preserving techniques that comply with data protection laws.

CCS Concepts: • **Human-centered computing** → **Ubiquitous and mobile computing**; • **Security and privacy** → **Human and societal aspects of security and privacy**.

Additional Key Words and Phrases: Internet of Things, Privacy by Design, Privacy Law, Programming Environment, Human-centered Design, Software Engineering

## 1 INTRODUCTION

Due to the potential of Internet of Things (IoT) applications to derive sensitive information about individuals [46], developers<sup>1</sup> must exercise due diligence so that users' privacy is protected in accordance with the regulations of data protection law. However, doing so can be a difficult and challenging task. Recent research has revealed that developers typically face difficulties when complying with regulations when they are vague, and where it is difficult to extract and enact such legal requirements [4]. It is essential to note that developers often do not put privacy first [1, 5, 25], as well as having a lack of understanding of the necessity of putting it in place for data privacy and protection purposes [18]. There is, moreover, a lack of practical guidance that considers the technical domain for developers to build a-privacy-aware IoT application [23].

Building an IoT application is a complex process compared to desktop, mobile, or web applications [12]. This is due to the IoT containing various physical objects or nodes of different computing, sensing, and actuation capabilities, along with being able to communicate between each other and other systems in order to gather and exchange data [46]. The heterogeneous nature of IoT necessitates that both software and hardware should work together, for example sensors and actuators, across a variety of nodes, including mobile phones and cloud platforms, due to them having varying capabilities depending on different conditions [45]. The complexity of IoT architecture results in a lack of integrated development stacks, with different software engineering specialists collaborating to support end-to-end IoT applications [44].

Privacy concerns are not always properly considered due to engineering complexities, even though there may be isolated solutions [61, 63] for software processes during the design and development of IoT applications. In addition, studies have revealed that developers with various backgrounds tend to lack the skills to effectively implement privacy management [6, 59], and the difficulties around complying with regulations are likely to increase in the future [5]. Even though guidelines are available, they usually focus on legal aspects, and not technical requirements, leaving them disconnected from the environment that developers work in, as well as the tools they use to build applications. Thus, developers face the problem of relating the guidance provided to actual technical considerations, such as ensuring a specific design or its implementation properly meets privacy requirements.

Privacy by Design (PbD) [21] is a fairly new system that works to embed privacy practice more deeply and effectively into the development process [24, 54]. REGULATION (EU) 2016/679 General Data Protection Regulation (GDPR) [58] confirms the importance of this and is applicable to all systems that manage personal data processing - a common feature of IoT applications. The contribution of this paper is as follows:

- An analysis of various data protection laws, which are: General Data Protection Regulations (GDPR), the Personal Information Protection and Electronic Documents Act (PIPEDA), California Consumer Privacy Act (CCPA), Australian Privacy Principles (APPs), and New Zealand's Privacy Act 1993, through the framework analysis method [55] used to attain a comprehensive view of various data protection laws and highlight the disparities. This will assist developers in adhering to the regulations across different regions. Subsequently, a Combined Privacy Law Framework (CPLF) was created which was then used for the following tasks (CPLF is presented in Section 4 and discussed in details in Appendix B).
- The key principles and individuals' right of the CPLF were mapped with the well-known Privacy by Design (PbD) schemes (e.g., privacy principles, strategies, guidelines, and patterns) developed by different researchers in the past in order to investigate the gaps in existing schemes.

<sup>1</sup>In this paper, the terms software developers, developers, or software engineers are used interchangeability.

- Furthermore, this research provides an insight into how to apply privacy patterns to the IoT architecture during the software design phase. Several different case scenarios were used to demonstrate how developers could use privacy patterns to comply with data protection laws. Finally, the research challenges and opportunities were identified.

**Paper Structure.** The paper contains nine sections and is structured as follows: Section 1 presents the introduction, contributions, and paper structure. Section 2 gives an overview of privacy laws. Section 3 presents the analysis process for the data protection laws of various countries using framework analysis. Section 4 presents an overview of the key principles and individuals' rights that resulted from the analysis process (i.e., Combined Privacy Law Framework (CPLF)). Section 5 discusses the results of the analysis of the various data protection laws. Section 6 presents an overview of Privacy by Design (PbD) and correlates the principles and rights of the CPLF and the principles, strategies, guidelines, and patterns of the PbD schemes. In Section 7, the IoT architectures of two scenarios are presented, and the position of the privacy patterns are demonstrated in these IoT architectures. Section 8 discusses the research challenges and opportunities. Finally, Section 9 sets out the conclusion.

## 2 OVERVIEW OF THE PRIVACY LAWS

This section presents an overview of various data protection laws with their key principles and rights, which are: General Data Protection Regulations (GDPR), the Personal Information Protection and Electronic Documents Act (PIPEDA), California Consumer Privacy Act (CCPA), Australian Privacy Principles (APPs), and the New Zealand Privacy Act (1993) to present a comprehensive view of some of the data protection laws of key countries around the world, and to highlight any disparities, in order to assist developers in adhering to the regulations across different regions. It is important to understand each of these major privacy laws individually, before moving on to analyse them together in the subsequent sections.

### 2.1 The General Data Protection Regulation (GDPR)

These regulations have applied since the 25th of May 2018, although they were entered into force on the 24th of May 2016. Their applicability under the General Data Protection Regulations means that there is a single set of data protection rules that all companies operating within the EU must adhere to. These regulations have strengthened the rights of individuals in accordance with the current digital age, along with providing clarity to businesses and public bodies operating within the single digital market of the EU. The key principles and rights of the GDPR are as follows [58]: **Key Principles:** (1) *Lawfulness, fairness and transparency*, (2) *Purpose limitation*, (3) *Data minimisation*, (4) *Accuracy*, (5) *Storage limitation, Disclosure, and Retention*, (6) *Integrity and confidentiality (security)*, and (7) *Accountability*; **Individuals' Rights:** (1) *The right of individuals to exercise their rights*, (2) *The right to be informed*, (3) *The right of access*, (4) *The right to rectification*, (5) *The right to erasure*, (6) *The right to restrict processing*, (7) *The right to data portability*, (8) *The right to object*, and (9) *The rights in relation to automated decision making and profiling*.

### 2.2 The Personal Information Protection and Electronic Documents Act (PIPEDA)

The Personal Information Protection and Electronic Documents Act (PIPEDA) was introduced in Canada and became law on the 13<sup>th</sup> of April 2000; it addresses federal privacy law for organisations in the private sector. The ground rules for how businesses should deal with personal information as part of their commercial activities, are set out. The act gives individuals more control over how the private sector handles their personal information [33]. The key principles [42] and rights [37] of the PIPEDA are as follows: **Key Principles:** (1) *Accountability*, (2) *Identifying Purposes*, (3) *Consent*,

(4) *Limiting Collection*, (5) *Limiting Use, Disclosure, and Retention*, (6) *Accuracy*, (7) *Safeguards*, (8) *Openness*, (9) *Individual Access*, and (10) *Challenging Compliance*; **Individuals' Rights**: PIPEDA states that (1) *Private sector organisations must gather, and use or disclose, personal information using appropriate fair and lawful means, including gaining consent, and for reasonable and clear purposes*, (2) *Organisations must protect people's personal information by implementing effective security measures, and this data must be destroyed once it is no longer needed*, (3) *The individual has the right to expect that any personal information an organisation has about them is accurate and up to date*, (4) *The person has the right to see it, and if it is inaccurate, request that corrections are made*, and (5) *The person also has the right to withdraw their consent at any time, in accordance with legal or contractual restrictions and following reasonable notice*.

### 2.3 California Consumer Privacy Act (CCPA)

The right of privacy for Californians is granted by the California Constitution, which provides consumers with an effective way of controlling their personal information through upholding specific rights. This bill enacts the California Consumer Privacy Act of 2018, starting on January 1<sup>st</sup>, 2020. **Key Principles**: the CCPA grants Californians rights rather than principles [22]. **Individuals' Rights**: (1) *Californians have the right to know what personal information an organisation is collecting about them*, (2) *Californians have the right to know if their personal information has been sold or disclosed, and to who*, (3) *Californians have the right to refuse the sale of their personal information*, (4) *Californians have the right to gain access to their personal information*, and (5) *Californians have the right to equal services and prices, including if they decide to exercise these privacy rights*.

### 2.4 Australian Privacy Principles (APPs)

Australian Privacy Principles (APPs) provide the main privacy protection framework in the Privacy Act 1988 (Privacy Act), and they are applicable to all organisations and agencies that the Privacy Act covers. This gives the organisation or agency the flexibility to design their practices on personal information for inclusion in their business model to meet the varied needs of individuals [26]. The key principles [28] and rights [29] of the Privacy Act are as follows: **Key Principles**: (1) *Open and transparent management of personal information*, (2) *Anonymity and pseudonymity*, (3) *Collection of solicited personal information*, (4) *Dealing with unsolicited personal information*, (5) *Notification of the collection of personal information*, (6) *Use or disclosure of personal information*, (7) *Direct marketing*, (8) *Cross-border disclosure of personal information*, (9) *Adoption, Use or Disclosure of an identifier*, (10) *Quality of personal information*, (11) *Security of personal information* (12) *Access to personal information*, and (13) *Correction of personal information*; **Individuals' Rights**: the Privacy Act gives individuals more control over the way their personal information is managed, as it allows the person to: (1) *Find out why their personal information is being collected, and how it will be used, as well as who it will be disclosed to*, (2) *The option of not being identified or using a pseudonym if possible*, (3) *Request access to their personal information, including health information*, (4) *Stop being sent unwanted direct marketing material*, (5) *Request that any personal information that is incorrect is corrected*, and (6) *Put in a complaint about an organisation or agency that the Privacy Act covers if they believe that their personal information has been handled inappropriately*.

### 2.5 New Zealand's Privacy Act 1993

The Privacy Act controls the way that agencies collect, use, disclose, store and provide access to individuals' personal information, and is relevant to all government departments, different size companies, schools, religious groups and clubs in New Zealand [35]. The key principle [39] and rights [36] of the Privacy Act are as follows: **Key Principles**: (1) *Purpose of collection* (2) *Source of information*, (3) *What to tell an individual*, (4) *Manner of collection*, (5) *Storage and security*, (6)

Access, (7) *Correction*, (8) *Accuracy*, (9) *Retention*, (10) *Use*, (11) *Disclosure*, and (12) *Unique identifiers*; **Individuals' Rights:** the Privacy Act gives the right to: (1) *Access your information* and (2) *Ask for correction when it is wrong*.

### 3 ANALYSIS OF THE DATA PROTECTION LAWS OF VARIOUS COUNTRIES USING A FRAMEWORK ANALYSIS METHODOLOGY

The framework analysis [15] method has been developed by qualitative specialist researchers from the UK who work for an independent social research institute. The method involves five distinct phases, which are interlinked and provide a thorough methodical framework: (1) the familiarisation process, (2) developing a theoretical framework, (3) indexing, (4) charting and (5) synthesising the data. These phases allow the researcher to understand and interpret the data, shifting from mainly descriptive accounts to a conceptual explanation of the situation. Figure 1 presents an overview of the analysis process. The analysis in this research is based on the latest version of each law.

#### 3.1 The Method

**3.1.1 Familiarisation process:** In the first stage, all the regulations from the data protection laws of the selected countries are read in order to attain a good understanding of these data protection laws.

**3.1.2 Developing a theoretical framework:** For the second stage, after becoming familiar with all five regulations, two key themes emerged to identify principles and rights. Each regulation from these issuers was read to identify its principles and rights. Using the Airtable tool, all the principles of a specific issuer were grouped together as sub-themes of the key theme principles in a single table, as well as the rights, where all the rights of a specific issuer were grouped together under the main themes. If there were two matching principles of different laws, the general name of a principle was chosen to identify that sub-theme. This step has been developed in stages by developing a theoretical framework containing all of the data protection laws from the countries specified above.

**3.1.3 Indexing:** This stage included a thorough reading of all the regulations. Since there are some variations in the concept of a specific principle or right between different issuers, a section was created for each sub-theme using the OneNote app in order to compare between the various issuers' laws concerning a specific principle/right. Each section was filled out using the defined principle or right of a specific law. If the issuer does not have a matched principle or right, the whole regulations would be read to find any matched provisions that could be assigned as the issuer's view of this principle/right. If there is no provision that can be assigned as the issuer's view, N/A (Not Applicable) was assigned to that principle or the right of that regulation. Hence, the final table was developed in stages as part of the indexing process.

**3.1.4 Charting:** Once the data was indexed in accordance with the theoretical framework, it was summarised in thematic charts by cutting down the original data to form manageable sections of text which could be easily understood, before placing the appropriate theme into the theoretical framework chart. After filling out all of the principles or rights with the matching text, a general definition was given to each principle or right in order to gain an overview of the meaning of each, regardless of the slight differences between regulations. The charts were devised on a Word document. Each chart contains fields for the following information: (i) *Definition of a principle/right*, (ii) *The issuers' names*, (iii) *The article's number, recital name, principle number, or principle name*,

(iv) *The name of the principle in that law*, and (v) *The quoted text that clarifies issuers' views on a specific principle/right*.

3.1.5 **Synthesising the data:** This phase involved reviewing the charts to ensure the data set made sense, before checking that the summaries on the charts matched the original data and conducting a comparison between the themes and sub-themes. This phase facilitated further revision of the quoted text from the regulation that was assigned to a specific law.

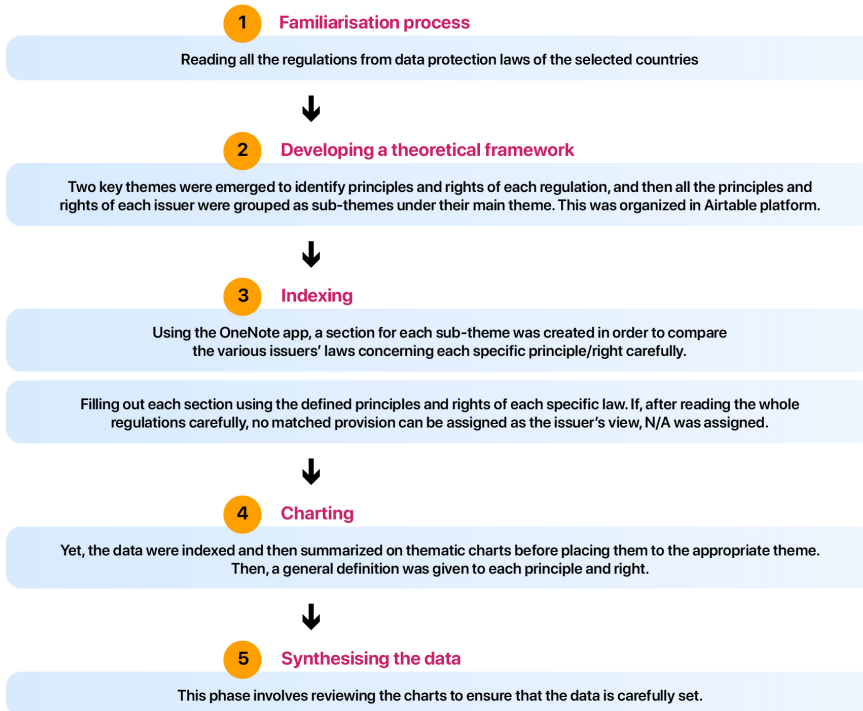


Fig. 1. Overview of the Analysis of the Data Protection Laws

## 4 RESULTS

This section presents an overview of each key principle and right that resulted from the analysis process, as explained in the previous section. The detailed results of the Combined Privacy Law Framework (CPLF)<sup>2</sup> are presented in Appendix B.

### 4.1 Key principles

13 key principles emerged from the analysis process and have been defined as follows:

- (1) **Transparency principle:** The organisation must provide detailed information on its policies and procedures concerning the management of personal information, and this must be readily available to the public.

<sup>2</sup>Combined Privacy Laws Framework refers to the selected data protection laws for this study.

- (2) **Purpose Limitation Principle:** The purposes that the personal information is being collected and is used for must be shared by the organization, either prior to or at the time it is collected.
- (3) **Limiting Use and Disclosure Principle:** An organisation may only use or disclose personal information for the purposes for which it was collected.
- (4) **Data Minimisation Principle:** Where personal data is required, it must be relevant, adequate and limited only to what is needed for the purpose stated.
- (5) **Consent Principle:** The individual's consent is required for the collection, use, and/or disclosure of their personal information.
- (6) **Lawfulness of Processing Principle:** Personal information must be processed by fair and lawful means.
- (7) **Accuracy Principle:** Attempts must be made to ensure that personal information is as accurate, complete and up-to-date as possible to ensure it satisfies the purposes for which it will be used.
- (8) **Storage Limitation Principle:** Personal information must not be stored for longer than necessary once it has met the purposes for which it was collected.
- (9) **Security Principle:** Safeguarding procedures must be in place to protect personal information and prevent its loss, misuse or disclosure.
- (10) **Accountability Principle:** An organisation is responsible for complying with all data protection laws concerning the personal information that is under its control, and it must appoint someone to be accountable for complying with the law in this area.
- (11) **Anonymity and Pseudonymity Principle:** Individuals must be given the option of not identifying themselves, or the choice of using a pseudonym, in relation to certain matters.
- (12) **Source Principle:** Unless there is an exception, personal information must be collected from the person the information is about.
- (13) **Cross-border Transfer of the Personal Information Principle:** Individuals' information is expected to be protected and handled appropriately, wherever the processing takes place.
- (14) **Dealing with Unsolicited Personal Data Principle:** An organisation must take reasonable steps to manage unsolicited personal information. Unsolicited personal information is 'personal information received by an entity that has not been requested by that entity.'
- (15) **Adoption, Use or Disclosure of an identifier Principle:** Adopting, using, or disclosing a unique identifier that was created for an individual for a different purpose should be prohibited.

## 4.2 Individuals' Rights

11 Individuals' rights emerged from the analysis process and have been defined as follows:

- (1) **Right of Individuals to Exercise their Rights:** Individuals shall have the right to exercise their data protection rights.
- (2) **Right to be Informed:** Individuals must be informed about the collection, use and/or disclosure of their personal information.
- (3) **Right of Individuals Access:** Individuals have the right to access the personal information which an organisation is holding about them.
- (4) **Right to Rectification:** Individuals shall have the right to ask for correction of their personal data.
- (5) **Right to Erasure:** Individuals shall have the right to ask for deletion of their personal data.
- (6) **Right to Restriction of Processing:** Individuals shall have the right to restrict the processing of their personal data.



- (7) **Right to Object:** Individuals shall have the right to object to the processing of their personal data.
- (8) **Right to Object to Marketing:** Individuals shall have the right to reject the processing of their personal data for direct marketing purposes.
- (9) **Right to Data Portability:** Individuals shall have the right to receive their personal data in a readily useable format that allows the individual to transmit the information to another organisation.
- (10) **Right to Object to Automated Decision-Making:** Individuals must have the right to object to a decision that is based solely on automated processing.
- (11) **Right to Withdraw Consent:** Individuals shall have the right to withdraw consent at any time.
- (12) **Right to Complain:** Every data subject shall have the right to lodge a complaint.
- (13) **Right of Individuals not to be Discriminated:** A business shall not discriminate against a consumer because the consumer exercised any of their rights.

## 5 DISCUSSION

This section discusses the results of the comparison between the GDPR, PIPEDA, CCPA, Australia's Privacy Act 1988, and New Zealand's Privacy Act 1993 (the detailed results of the CPLF are presented in Appendix B). The Table 1 and Table 2 show an overview of the similarities and differences between the principles of the data protection laws selected for this study.

### 5.1 Scope of the Laws

The GDPR contains fully comprehensive data protection laws, although federal privacy law in the US, including the CCPA, are viewed as being the most important legislation on privacy developments in the country. Furthermore, while all of these five laws have similar core legal frameworks that aim to protect individuals' data, the CCPA is different from the other laws in a number of ways as it covers a different scope. In particular, this means that the GDPR, PIPEDA, APPs, and New Zealand Privacy Act (1993) articulate rules for organisations to comply with when processing personal data to protect individuals' privacy. The CCPA, however, only concerns individuals' rights, rather than guiding organisations.

As mentioned previously, the GDPR has a far wider scope compared to other laws. While the scope of New Zealand's Privacy Act (1993) is limited to its agencies, and the scope of the CCPA only covers businesses that do business in California and process Californian residents' data, the GDPR is applicable to all businesses, public bodies and institutions, including not-for-profit organisations. That is, an organisation that has been established in the EU and processes personal data, regardless of the location where that data is processed; organisations established outside of the EU that offer goods or services, whether paid for or free, or those monitoring the behaviour of individuals living in the EU. APPs has similarities to these scopes since it applies only to APPs' entities, and it covers acts that have been completed or engaged in, including those outside Australia and the external territories, where the organisation has a link to Australia [31]. The PIPEDA, however, is restricted only to commercial organisations and for-profit activities, [40] and is applied to personal data that moves across provincial or national borders as part of the commercial transactions that organisations are involved in - subject to the act or similar legislation [38].

### 5.2 Key Principles

The CPLF is to a large extent similar in relation to their principles, even though they use different terms for naming those principles, and embed one principle under another one, have different

conditions, or are broader than others (as highlighted in Appendix B). However, the CCPA differs from the other laws, as its primary focus is on sharing and selling rather than collection.

**5.2.1 Transparency principle:** With regard to the transparency principle, the GDPR, PIPEDA, APPs, and New Zealand's Privacy Act (1993) assert that the privacy policy has to be clear and easily accessible. In contrast, the CCPA does not mention this explicitly - only as a general desire for its data practices.

**5.2.2 Purpose Limitation, Data Minimisation, and Limiting Use and Disclosure Principles:** The GDPR, PIPEDA, APPs, and New Zealand's Privacy Act emphasise the need for the purpose of data collection to be stated before or during the time of collection. They require data to be collected for clearly specified legitimate purposes, and not used beyond that (used or disclosed) in a way that is not in line with the purposes set out. They also emphasise that the collection of personal information has to be limited only to what is necessary to fulfil the stated purpose. The APPs and New Zealand's Privacy Act clarify that the collection of personal information should be linked to a function or activity conducted by the organisation. However, the provision of the GDPR is wider, as it allows additional processing to archive data that is in the public interest; for scientific or historical research purposes, or for statistical reasons. Nevertheless, this must be done in accordance with specific conditions that are not incompatible with the purposes originally stated. Even though the CCPA does not have an equivalent provision that requires businesses to specify or identify its purposes, it asserts that it is mandatory to give the consumer notice when collecting or using extra categories of personal information for other purposes.

**5.2.3 Storage Limitation Principle:** Regarding storage limitation principle, the GDPR, PIPEDA, APPs, and New Zealand's Privacy Act assert that organisations must not keep personal information for longer than necessary, and it must be used only for the reasons it was collected for. The PIPEDA and APPs suggest destroying, erasing, or anonymising all personal information that an organisation no longer requires. The GDPR, however, allows personal data to remain if it needs to be archived. In contrast, the CCPA does not set out clear provisions for businesses for data retention, whereas service providers and third parties are prohibited from keeping, using, or disclosing personal information for any reason other than those specified for the services set out in the original business contract.

**5.2.4 Consent Principle:** While the GDPR, PIPEDA, CCPA, and APPs intrinsically require the consent of the individual for the collection, use and disclosure of personal information, their definitions of the word consent vary. The GDPR states that informed consent must be given freely, and its use must be specific and unambiguous; in addition, APPs bases consent on four elements: the individual is properly informed prior to giving consent; they provide consent voluntarily; consent is current and for a specific objective, and the individual must have the ability and capacity to understand and provide that consent. In a similar way, PIPEDA asserts that the consent should be meaningful. The CCPA, however, allows businesses to sell data from minors based on consent, although this is only in reference to the sale of information, and is not required for collecting the information. All these laws articulate provisions regarding consent to process children's data (as clarified in Table 13 in Appendix B). In contrast, New Zealand's Privacy Act does not require consent to be obtained by the agency, and it does not specify if consent to collect the information needs to be provided. In addition, it does not differentiate between information collected from adults or children. However, it does require agencies to take reasonable steps to ensure that the person is aware that they are collecting information from them.

**5.2.5 Lawfulness of Processing Principle:** The main operational differences between the GDPR and other laws discussed here concern the various approaches to the legal requirements to process data. The GDPR is much broader compared to the other laws as it allows organisations to gather, use and disclose personal information as long as one of the six grounds contained in Article 6 is met. Unlike the PIPEDA, APPs, and New Zealand's Privacy Act, they only require the collection of personal data to be lawful as a legal obligation. The CCPA, nevertheless, does not provide a clear list of grounds that organisations must adhere to collect information. It only requires businesses to maintain and use the consumer's personal information where necessary, for internal use, in a lawful manner that adheres with the context in which the consumer provided the information if none of the eight specified conditions is satisfied. With regard to the quality of the data, the accuracy of personal information is not considered under the CCPA, and neither is the ability of individuals to correct their information; whereas all the other laws in this study require personal data to be accurate, complete and up to date.

**5.2.6 Security Principle:** All the data protection laws in this research assert that organisations must ensure appropriate security when processing personal data. In case of any data breach, it is mandatory for organisations to notify the responsible authorities and individuals; unlike New Zealand's Privacy Act (1993), where data breach notification is voluntary. However, the New Zealand government's new Privacy Act will set out a requirement for data breaches to be reported.

**5.2.7 Accountability Principle:** Regarding the accountability principle, organisations are responsible for complying with all data protection laws, including those for personal information under their control. The GDPR, PIPEDA, APPs, and New Zealand's Privacy Act (1993) also set out requirements regarding the appointment of data protection (privacy) officers, to ensure that they are obliged to follow the law. Nonetheless, the CCPA does not focus on obligations related to accountability specifically, although a business or third party can ask the opinion of the Attorney General to obtain guidance on how to properly comply with the provision.

**5.2.8 Anonymity and Pseudonymity Principle:** The APPs includes a key principle regarding anonymity and pseudonymity, allowing individuals to have the option of not being identified, or the use of a pseudonym, that is, provided there is no listed exception applicable. The CCPA does not clarify whether its obligations are applicable to personal information that has been given a pseudonym. As with the GDPR and PIPEDA, their provisions contain no direct analog about applying anonymity and pseudonymity where the organisation no longer needs to process personal data. New Zealand's Privacy Act does not, however, have an equivalent principle.

**5.2.9 Source Principle:** Both the APPs and New Zealand's Privacy Act require collecting personal information directly from the individual, unless an exception applies. The GDPR does not have a similar principle, however, the data controller must provide the subject whose data they are dealing with, with information if that personal data has not been obtained directly from them. In the same way, provisions in the PIPEDA and CCPA require organisations to declare the source of this information should the individual request it.

**5.2.10 Cross-border Transfer of the Personal Information Principle:** The cross-border transfer of personal information is permitted under the GDPR, PIPEDA, APPs, and New Zealand's Privacy Act (1993). They require that the rules that protect personal data apply on an ongoing basis, wherever the data ends up, and it is required to take reasonable steps to prevent any overseas recipient from breaching the regulations covering the information. In contrast, the CCPA does not restrict a business collecting or selling personal information if all aspects of that commercial conduct are conducted outside California.

**5.2.11 Dealing with Unsolicited Personal Data Principle:** APPs has a key principle regarding the case of dealing with unsolicited personal data, as an entity is required to destroy or de-identify information that may not have otherwise been collected in accordance with the collection of solicited personal data. This situation, however, is not mentioned in all the other laws.

**5.2.12 Adoption, Use or Disclosure of an identifier Principle.** When it comes to adopting a unique identifier, whether it is a government related identifier or an identifier that was created for a different purpose, this is prohibited by the PIPEDA, APPs, and New Zealand’s Privacy Act. This is unlike the GDPR, which sets out specific conditions for processing national identification numbers and any other identifiers of general application, and restricts using it under relevant safeguarding guidelines. In contrast, the CCPA does not mention any regulations related to this principle, and this could be related to the nature of its legislation.

Table 1 shows an overview of the similarities and differences between the principles of the data protection laws selected for this study according to the following criteria:

✓	If the issuer’s view agrees with the concept of this key principle/right
☑	If the issuer’s view is not explicitly stated but agrees with the concept of this key principle/right being inferred from such a provision
N/M	If a regulation contains an explicitly stated provision for a different context from this key principle/right
N/A	If no provision can be assigned as the issuer’s view and there is no contradiction with this principle/right

Table 1. Overview of the Principles

Principle	GDPR	PIPEDA	CCPA	APPS	New Zealand
Transparency	✓	✓	☑	✓	✓
Purpose Limitation	✓	✓	✓	✓	✓
Limiting Use, Disclosure	✓	✓	✓	✓	✓
Data Minimisation	✓	✓	✓	✓	✓
Consent	✓	✓	✓	✓	N/A
Lawfulness of processing	✓	✓	☑	✓	✓
Accuracy	✓	✓	N/A	✓	✓
Storage Limitation	✓	✓	☑	✓	✓
Security	✓	✓	☑	✓	✓
Accountability	✓	✓	✓	✓	✓
Anonymity and Pseudonymity	N/M	N/M	N/M	✓	N/A
Source	✓	✓	✓	✓	✓
Cross-border Disclosure of Personal Information	✓	✓	N/A	✓	✓
Dealing with Unsolicited Personal Information	N/A	N/A	N/A	✓	N/A
Adoption, Use or Disclosure of an identifier	✓	✓	N/A	✓	✓

### 5.3 Individuals' Rights

There are similarities and differences between the rights of the CPLF, which will be discussed below (based on the detailed results shown in Appendix B).

**5.3.1 *Right of Individuals to Exercise their Rights:*** Individuals have the right to exercise their rights. All the laws in this study require organisations to ensure the exercise of individual rights and to take reasonable steps to put practices, procedures and systems in place that enable them to deal with relevant inquiries and complaints, even though they have differences regarding the way and the condition of responding to individuals' requests.

**5.3.2 *Right of Individuals Access:*** Regarding individuals' right of access, all the privacy laws grant right of access if a request is made by an individual, unless there is an exception, thereby allowing the individual to view all of the data an organisation is holding about them. Individuals may obtain details about the data that is being processed, and can have access to copies of the data that concerns them. Accessing the information is free of charge, at least for the first time, except for PIPEDA, which allows organisations to grant individuals free access or charge them a minimal fee. There are, furthermore, some differences, such as regarding the procedure organisations must comply with to respond to an individual's request.

**5.3.3 *Right to Rectification:*** Based on the individuals' right of access, the GDPR, PIPEDA, APPs, and New Zealand's Privacy Act provide individuals the right of correction of personal data that an organisation holds. The GDPR sets out a stronger right, as subjects have the 'right to obtain from the controller without undue delay the rectification to inaccurate personal data concerning him or her'. In contrast to the CCPA, which does not have an equivalent right.

**5.3.4 *Right to be Informed:*** All of the privacy laws in this study contain prescriptive provisions about the information organisations must provide when collecting and processing individuals' personal information. Moreover, all of the legislation states when information should be provided to individuals and what they should be told about. On the other hand, the GDPR, the CCPA, PIPEDA, APPs, and New Zealand's Privacy Act do not distinguish between the notice given for collecting information directly from individuals, and the notice necessary for information obtained from other sources.

**5.3.5 *Right to Erasure:*** The GDPR and the CCPA both permit individuals to ask for the deletion of their personal information, apart from where exceptions apply. This right is similar in both pieces of legislation, although the applicability and exemptions are slightly different. The GDPR contains the right to the erasure of information (sometimes called the right to be forgotten), and states that the data controller must erase personal data without any unnecessary delay in a range of situations, for example when it is no longer needed for the purpose it was collected, or if the subject withdraws their consent or objects to the information being processed. Regarding the PIPEDA, APPs, and New Zealand's Privacy Act, individuals do not have clear rights in these laws regarding organisations destroying or de-identifying their information. These laws, however, require organisations to destroy, erase or anonymise personal information that they do not need any more. The PIPEDA, nonetheless, states that it is obligatory for organisations to amend the information if an individual clearly demonstrates the personal information is inaccurate or incomplete. Depending on the nature of the information that is being challenged, the amendment may involve deletion, correction or the adding of information.

**5.3.6 *Right to Restriction of Processing:*** The GDPR grants individuals the right to restriction of processing for their personal data when one of the specified cases applies. In contrast, the

PIPEDA, CCPA, APPs, and New Zealand's Privacy Act do not contain the right to restrict data processing.

**5.3.7 Right to Object:** The GDBR and the CCPA guarantee the right to individuals to request that an organisation stops the processing and selling of their data. The CCPA allows consumers only to opt-out of their personal data being sold, and not collection or other uses that fall outside the definition of selling. In contrast, individuals are allowed to object to any type of processing of their personal data according to the GDPR, including by withdrawing consent or by objecting to its processing, provided the request is based on a legitimate reason, and does not affect the public interest. However, there are no similar provisions regarding the right to object in the PIPEDA, APPs, and New Zealand's Privacy Act. Rather, the provisions in these laws grant individuals the right to withdraw consent at any time. Moreover, for automated processing, while the GDPR grants individuals the right to object to a decision solely based on automated processing, none of the other laws in this study consider this a right.

**5.3.8 Right to Object to Marketing:** APPs states that an organisation cannot use or disclose personal information about an individual for direct marketing purposes, and organisations are required to provide a simple method for individuals to ask not to be sent direct marketing communications (known as 'opting out'). Similar to the GDPR, it grants data subjects, among other things, the right to object to their data being processed for direct marketing purposes. Like the CCPA, it is the consumer's right to opt-out of selling their personal information, as well as opting out from the subsequent sale of their personal information by a third party that is given the personal information after its initial sale. In contrast, both the PIPEDA and the New Zealand Privacy Act do not have an equivalent right to object to personal data being used for direct marketing purposes.

**5.3.9 Right to Data Portability:** The GDPR and the CCPA recognise the right to data portability, as the CCPA views data portability as being part of the right to access, and the GDPR sets out a separate and distinct right. The PIPEDA, APPs, and New Zealand Privacy Act, nevertheless, do not provide equivalent rights to data portability.

**5.3.10 Right to Withdraw Consent:** All the laws in this study grant individuals the right to lodge a complaint, even though they have differences in their procedures. The PIPEDA, APPs, and New Zealand's Privacy Act encourage individuals, if they have concerns about their personal information being mishandled, to firstly resolve privacy issues directly with the organisation. This is unlike the GDPR and the CCPA, which suggest lodging a complaint to a supervisory authority or to the Attorney General, respectively.

**5.3.11 Right of Individuals not to be Discriminated:** In respect of protecting individuals from any consequences, the CCPA contains the right to not be subject to discrimination when exercising their rights, but this right is not explicitly stated in the other laws mentioned.

Table 2 presents an overview of the similarities and differences between the rights of the data protection laws selected for this study according to the following criteria, which is the same as the criteria that were applied to the principles before:

## 6 PRIVACY LAWS AND PRIVACY BY DESIGN SCHEMES

In the previous sections, a Combined Privacy Law Framework (CPLF) was developed by analysing and synthesising five major Privacy laws together. This section presents an overview of Privacy by Design (PbD) techniques and correlates these privacy techniques with the principles and the rights of the CPLF in order to investigate the gap in the previous techniques.

✓	If the issuer's view agrees with the concept of this key principle/right
☐	If the issuer's view is not explicitly stated but agrees with the concept of this key principle/right being inferred from such a provision
N/M	If a regulation contains an explicitly stated provision for a different context from this key principle/right
N/A	If no provision can be assigned as the issuer's view and there is no contradiction with this principle/right

Table 2. Overview of the Rights

Individual Rights	GDPR	PIPEDA	CCPA	APPS	New Zealand
Right of Individuals to Exercise Their Rights	✓	✓	✓	✓	✓
Right to be Informed	✓	✓	✓	✓	✓
Right of Individuals Access	✓	✓	✓	✓	✓
Right to Rectification	✓	✓	N/A	✓	✓
Right to Erasure	✓	☐	✓	N/M	N/M
Right to Restriction of Processing	✓	N/A	N/A	N/A	N/A
Right to Object	✓	☐	☐	☐	☐
Right to Object to Marketing	✓	N/A	☐	✓	N/A
Right to Data Portability	✓	N/A	✓	N/A	N/A
Right to Object to Automated Decision-Making	✓	N/A	N/A	N/A	N/A
Right to Withdraw Consent	✓	✓	✓	✓	✓
Right to Complain	✓	✓	✓	✓	✓
Right of individuals not to be Discriminated	N/A	N/A	✓	N/A	N/A

## 6.1 Privacy by Design

This section presents an overview of the Privacy by design (PbD) concept that was developed by Cavoukian [10]. The privacy, as well as friendliness, of IT systems can be improved by the Privacy by Design (PbD) system [10] according to its design philosophy. Moreover, the system design has a major impact on privacy and security, which is a key issue affecting the core property of a system. Therefore, privacy protection is not something that should be considered to be an add-on; rather, privacy should take priority from the outset.

Perera et al., explain the various terms used in the literature on privacy by design (PbD) techniques, such as principle, strategies, patterns, and tactics [44]. As demonstrated in Figure 2, principles may represent high level, even abstract, ideas and concepts [44]. On the other hand, tactics are specific low level instructions required to implement solutions within a particular context. Furthermore, strategies, guidelines and patterns are situated between these. It should be borne in mind that the difference does not make one type better or worse than the other, as each layer has its own specific strengths and weaknesses. That is, bottom layer tactics facilitate specific solutions to solve specific problems, compared to top layer principles which give insights concerning the general direction that can be taken for further exploration and to solve problems. However, it should be noted that there are some soft boundaries between these layers, as some principles can be interpreted as strategies and vice-versa [44].

**Principle:** A principle provides a conceptualisation or value used for guiding behaviour or an evaluation. They are usually highly abstract, but provide the overall direction to be followed [44].

**Strategies:** Unlike principles, strategies focus on reaching a specific outcome, and the design strategy sets out the main approach that should be used to reach a particular design goal. This makes strategies more specific with regard to their aims and goals [19].

**Guidelines:** Guidelines are used to break down the strategy being followed into lower-level clear instructions that can be followed by the software engineer [44].

**Patterns:** Design patterns provide a useful way of making decisions about the software system used by an organisation. A design pattern provides a scheme for refining the subsystems or components of a software system, or the relationships between them. It describes a commonly recurring structure of communicating components that solves a general design problem within a particular context [8].

**Tactics:** Tactics are used to build patterns; to explain, if we imagine a pattern is a molecule, a tactic is an atom made up of the former [7]. That is, patterns are made up of several tactics combined to solve a certain problem. Tactics assist in fine tuning patterns and usually focus on specific attributes and influence trade-off decisions [44].



Fig. 2. Privacy by Design (PbD) Schemes

## 6.2 Mapping between the Combined Privacy Laws Framework and Privacy by Design Schemes

Privacy by Design (PbD) schemes are produced by various parties (PbD schemes are listed in Appendix C). Even though all of these schemes aim at guiding software designers and developers to build privacy aware applications, each party has its own frame. Because there are numerous variations in originating contexts, as well as differing aims, each scheme is designed to be able to work in isolation without being fully connected to another. This disconnected view means that understanding different PbD schemes is hard, confusing and frustrating, as is proposing new schemes to fill any existing gaps. Furthermore, these schemes are not only disconnected from each other, but they are also disconnected from the CPLF. Accordingly, this section addresses this issue by synthesising and modelling key PbD schemes into one single knowledge base. The knowledge base not only captures the relationship between various privacy schemes, but it also correlates the principles, guidelines, and strategies of the PbD schemes with the principles and rights of the CPLF. This correlation is based on large similarities between the description of each principle and right of the CPLF, with the description of each principle, guideline, and strategy of the PbD schemes, as shown later in Tables 3, 4, 5, 6, and 7 (details are also presented in Appendix C).



**6.2.1 Mapping between the Combined Privacy Laws Framework and Privacy by Design Principles.**

In this section, the objective is to correlate the principles of the Privacy by Design (PbD) schemes with the key principles and individuals’ rights of the CPLF. According to Table 3. Cate [9] has proposed five principles (Appendix C.1.1), Cavoukian [10] has suggested seven privacy principles (Appendix C.1.2), and ISO/IEC 29100 [57] has issued 11 principles (Appendix C.1.3). According to Table 4, Cavoukian and Jonas [11] have proposed 7 principles (Appendix C.1.4), Wright and Raab [60] have created nine principles (Appendix C.1.5), and three principles have been issued by Fisk et al. [14] (Appendix C.1.6).

-- Begin of Table

Table 3. Mapping between the Combined Privacy Laws Framework and Privacy by Design Principles (Cate 2011, Cavoukian 2009, and ISO/IEC 29100 2011) (shortened form of the terminologies - see Appendix C for the full form of PbD principles and Section 4 for the full form of the CPLF)

Principles	Principles by Cate (2011) [9]					Principles by Cavoukian (2010) [10]					Principles by ISO/IEC 29100 (2011) [57]												
Privacy Laws/ Rights	0.1 Notice / Awareness ...	0.2 Choice / Consent	0.3 Access / Participation	0.4 Integrity / Security ...	0.5 Enforcement / Redress...	01. Proactive not Reactive; ...	02. Privacy as the ...	03. Privacy Embedded ...	04. Full Functionality...	05. End-to-End ...	06. Visibility and Transparency - ...	07. Respect for User ...	01. Consent and choice	02. Purpose legitimacy and ...	03. Collection limitation	04. Data minimisation	05. Use, retention, and ...	06. Accuracy and quality	07. Openness, transparency, ...	08. Individual participation ...	09. Accountability	10. Information Security	11. Privacy Compliance
Transparency	✓										✓		✓	✓					✓				
Purpose Limitation						✓	✓							✓									
Limiting Use, Disclosure				✓		✓	✓	✓								✓	✓						
Data Minimisation						✓	✓	✓							✓	✓							
Consent						✓		✓				✓	✓										
Lawfulness of Processing						✓		✓				✓	✓										
Accuracy			✓	✓		✓											✓			✓			
Storage Limitation						✓	✓	✓								✓	✓						
Security				✓		✓	✓	✓		✓													✓
Accountability					✓	✓	✓	✓	✓											✓	✓		✓
Anonymity ...						✓	✓	✓		✓					✓								
Source								✓															
Cross-border Disclosure ..						✓	✓																
Dealing ... Data						✓	✓																

-- Continuation of Table

Principles	Principles by Cate (2011) [9]	Principles by Cavoukian (2010) [10]	Principles by ISO/IEC 29100 (2011) [57]
<b>Privacy Laws/ Rights</b>	0.1 Notice / Awareness ... 0.2 Choice / Consent 0.3 Access / Participation 0.4 Integrity / Security ... 0.5 Enforcement / Redress...	01. Proactive not Reactive; ... 02. Privacy as the ... 03. Privacy Embedded ... 04. Full Functionality... 05. End-to-End ... 06. Visibility and Transparency - ... 07. Respect for User ...	01. Consent and choice 02. Purpose legitimacy and ... 03. Collection limitation 04. Data minimisation 05. Use, retention, and ... 06. Accuracy and quality 07. Openness, transparency, ... 08. Individual participation ... 09. Accountability 10. Information Security 11. Privacy Compliance
Adoption, .. identifier		✓	
.. Exercise Rights	✓		✓
Right to be informed	✓		✓
Right of .. Access	✓		✓
Right to Rectification	✓	✓	✓
Right to Erasure			✓
.. Restriction of Processing		✓	✓
Right to Object		✓	✓
.. Object to Marketing		✓	✓
Right to Data Portability			✓
.. Automated Decision ..		✓	✓
.. Withdraw Consent	✓	✓	✓
Right to Complain			✓
.. Discriminated			✓

End of Table

Regarding the relationship between the CPLF and the Privacy by Design (PbD) principles of Cate [9], Cavoukian [10], and ISO/IEC [57], Table 3 shows that most of the principles and rights of the CPLF are associated with many of these PbD principles. Interestingly, the principles of Cavoukian [10] tend to cover all the principles and rights of the CPLF compared to Cate [9], and ISO/IEC [57] principles. Cavoukian [10], furthermore, takes into consideration the interests of the individual under the principle of – **Respect for User Privacy; Keep it User-Centric** – as this principle achieves all the rights of the CPLF. This could simply return to the reason that Cavoukian [10] who first developed the concept of Privacy by Design. In contrast, **Consent, Lawfulness of processing, Storage limitation, and Anonymity and pseudonymity** principles of the

CPLF are not covered by the principles of Cate [9]. In addition, neither Cate [9] nor ISO/IEC [57] consider the following principles of the CPLF: **Source, Cross-Border Disclosure of Personal Information, Dealing with Unsolicited Personal Data, and Adoption Use or Disclosure of an Identifier**. With regard to the rights, while Cavoukian [10] covers all the rights of the CPLF, Cate [9] and ISO/IEC [57] have missed most of these rights.

-- Begin of Table

Table 4. Mapping between the Combined Privacy Laws Framework and Privacy by Design Principles (Cavoukian et al. 2012, Wright et al. 2014, and Fisk et al. 2015) (shortened form of the terminologies; see Appendix C for the full form of Pbd principles and Section 4 for the full form of the CPLF)

Principles	Principles by Cavoukian and Jonas (2012) [11]							Principles by Wright and Raab (2014) [60]							Principles by Fisk et al. (2015) [14]				
	1. Full Attribution	2. Data Tethering	3. Analytics on Anonymised ...	4. Tamper-Resistant ...	5. False Negative ...	6. Self-Correcting False ...	7. Information Transfer ...	01. Right to dignity	02. Right to be let alone	03. Right to anonymity	04. Right to autonomy	05. Right to individuality ...	06. Right to assemble or associate ...	07. Right to confidentiality and ...	08. Right to travel ...	09. People should not ...	Principle of Least ...	Principle of Qualitative ...	Principle of Forward Progress
Transparency							✓							✓					
Purpose Limitation																			
Limiting Use and Disclosure														✓		✓		✓	
Data Minimisation				✓				✓	✓	✓	✓	✓							
Consent							✓	✓		✓	✓		✓	✓					
Lawfulness of Processing							✓	✓		✓	✓		✓	✓					
Accuracy	✓	✓				✓													
Storage Limitation																✓			
Security			✓	✓									✓						
Accountability							✓										✓	✓	
Anonymity and Pseudonymity			✓					✓	✓	✓	✓	✓							
Source																			
Cross-border Disclosure ...																			
Dealing with Unsolicited Data																			
Adoption ... an identifier																			
Right ... Exercise their Rights															✓				
Right to be informed							✓												

-- Continuation of Table

Principles	Principles by Cavoukian and Jonas (2012) [11]							Principles by Wright and Raab (2014) [60]							Principles by Fisk et al. (2015) [14]				
<b>Privacy Laws/ Rights</b>	1. Full Attribution	2. Data Tethering	3. Analytics on Anonymised ...	4. Tamper-Resistant ...	5. False Negative ...	6. Self-Correcting False ...	7. Information Transfer ...	01. Right to dignity	02. Right to be let alone	03. Right to anonymity	04. Right to autonomy	05. Right to individuality ...	06. Right to assemble or associate ...	07. Right to confidentiality and ...	08. Right to travel ...	09. People should not ...	Principle of Least ...	Principle of Qualitative ...	Principle of Forward Progress
Right of Individuals Access																			
Right to Rectification	✓	✓				✓													
Right to Erasure																			
Right to Restriction of Processing																			
Right to Object														✓					
Right to Object to Marketing																			
Right to Data Portability																			
Right to object to Automated ...																			
Right to Withdraw Consent																			
Right to Complain																			
Right ... not to be Discriminated															✓				

End of Table

According to Table 4, it seems that the principles of Cavoukian and Joans [11], Wright and Raab [60], and Fisk et al. [14] do not cover many of the CPLF’s principles. This could be due to the nature of these principles, as the principles of Cavoukian and Joans are concerned with directing technical outcomes. While these principles move consumer privacy issues away from a policy or compliance issue towards a business imperative [11], the principles and rights of the CPLF tend to be legal requirements rather than technical requirements. As a result, only some – **Transparency, Accuracy, Security, Accountability and Anonymity and pseudonymity** – of the CPLF principles are achieved. **Right to be Informed, and Right to Rectification** – are also covered. With regard to the principles of Wright and Raab [60], they do not aim at creating principles that cover all the privacy issues, but aim to identify further privacy principles for the existing privacy principles that could be applied to different types of privacy with consideration of the risks and harms of different types of privacy policies [60]. Accordingly, seven out of 15 CPLF principles have been achieved, as shown in Table 4, and only two of the CPLF rights are covered – **Right of Individuals to Exercise their Rights, and Right to Object**. Fisk et al. [14], in contrast, define three principles that focus on sharing security information between

organisations [14]. This results in achieving only three of the principles – **Limiting Use and Disclosure**, **storage Limitation**, and **Accountability** – of the CPLF and missing all of its rights.

**6.2.2 Mapping between the Combined Privacy Laws Framework and Privacy by Design Strategies.**

This section aims at correlating the strategies of Privacy by Design (PbD) and the key principles and individuals’ rights of the CPLF. According to Table 5, while six privacy strategies have been issued by Rost and Bock [53] (Appendix C.2.1), Hoepman [19] has created eight privacy strategies (see Appendix C.2.2).

-- Begin of Table

Table 5. Mapping between Privacy Laws and Privacy by Design Strategies (Rost et al. 2011, and Hoepman 2014) ((shorten form of the terminologies; see Section 4 for the full form of the CPLF)

Strategies	Strategies by Rost and Bock [53] (2011)						Strategies by Hoepman (2014) [19]							
	01. Availability	02. Integrity	03. Confidentiality	04. Transparency	05. Unlinkability	06. Ability to intervene	01. Minimise	02. Hide	03. Separate	04. Aggregate	05. Inform	06. Control	07. Enforce	08. Demonstrate
Transparency				✓							✓			
Purpose Limitation					✓								✓	
Limiting Use and Disclosure							✓							
Data Minimisation							✓	✓		✓				
Consent						✓						✓		
Lawfulness of Processing						✓						✓		
Accuracy		✓												
Storage Limitation							✓							
Security			✓					✓	✓	✓				
Accountability	✓			✓	✓	✓							✓	✓
Anonymity and Pseudonymity							✓	✓						
Source														
Cross-border Disclosure ...														
Dealing with Unsolicited Data														
Adoption, Use ... of an Identifier														
Right ... to exercise their Rights						✓						✓		
Right to be informed										✓				
Right of Individuals Access						✓						✓		
Right to Rectification						✓						✓		
Right to Erasure						✓						✓		
Right to Restriction of Processing						✓						✓		
Right to Object						✓						✓		
Right to Object to Marketing						✓						✓		
Right to Data Portability						✓						✓		

-- Continuation of Table

Strategies	Strategies by Rost and Bock (2011) [53]						Strategies by Hoepman (2014) [19]							
	01. Availability	02. Integrity	03. Confidentiality	04. Transparency	05. Unlinkability	06. Ability to intervene	01. Minimise	02. Hide	03. Separate	04. Aggregate	05. Inform	06. Control	07. Enforce	08. Demonstrate
<b>Continuation of Privacy Laws/ Rights</b>														
Right to object to Automated Decision-Making						✓						✓		
Right to Withdraw Consent						✓						✓		
Right to Complain														
Right ... not to be Discriminated														

End of Table

According to Table 5, Rost and Bock [53] have formulated new data protection goals which are classified in this paper under the strategy of PbD schemes as it has an equivalent meaning, where strategy achieves a certain design goal, as stated previously in Section 6.1. Hoepman [19] also defines eight PbD strategies from the perspective of an IT system, and considers legal requirements to be the point of departure. Accordingly, most of the principles and rights of the CPLF are covered by these strategies. More precisely, as shown in Table 5, these PbD strategies tend to cover more of the rights of the CPLF compared to the principles of CPLF. However, both strategies do not take into consideration the following principles of the CPLF: – **Source**, **Cross-border Disclosure of Personal Data**, **Dealing with Unsolicited Personal Data**, and **Adoption, Use, Disclosure of an Identifier**. While three strategies of Hoepman [19] cover the principle of – **Data Minimisation** –, none of Rost and Bock’s [53] strategies are concerned about the **Data Minimisation** principle. In addition, neither the – **Limiting Use and Disclosure** – nor – **Storage Limitation** – and – **Anonymity and Pseudonymity** – of the CPLF are achieved by Rost and Bock’s [53] strategies. This could simply refer to the perspective of Rost and Bock [53] as they claim that their strategies do not stand alone but should be combined together with the privacy by design principles to be a comprehensive and universally accepted concept [53]. By contrast, while Rost’s and Bock’s [53] strategies achieve the **Accuracy** principle, Hoepman’s [19] strategies do not.

**6.2.3 Mapping between the Combined Privacy Laws Framework and Privacy by Design Guidelines.** In this section, the guidelines by O’Leary [13] (Appendix C.3.1) and the guidelines by Perera et al.[44] (see Appendix C.3.2) are mapped to the key principles and individuals’ rights of the CPLF, as demonstrated in Tables 6 and 7.

-- Begin of Table

Table 6. Mapping between the Combined Privacy Laws Framework and Privacy by Design Guidelines (O’Leary 1995) [13] (shortened form of the terminologies; see Section 4 for the full form of the CPLF)

Guidelines	Guidelines by O’Leary (1995) [13]							
	01. Collection limitation	02. Data quality	03. Purpose specification	04. Use limitation	05. Security safeguards	06. Openness	07. Individual participation	08. Accountability
<b>Privacy Laws/ Rights</b>								
Transparency						✓		
Purpose Limitation			✓					
Limiting Use and Disclosure				✓				
Data Minimisation	✓							
Consent								
Lawfulness of Processing	✓							
Accuracy		✓						
Storage Limitation			✓					
Security					✓			
Accountability								✓
Anonymity and Pseudonymity								
Source								
Cross-border Disclosure of Personal Information								
Dealing with Unsolicited Data								
Adoption, Use or Disclosure of an identifier								
Right of individuals to exercise their rights							✓	
Right to be informed						✓		
Right of Individuals Access							✓	
Right to Rectification							✓	
Right to Erasure							✓	
Right to Restriction of Processing							✓	
Right to Object							✓	
Right to Object to Marketing							✓	
Right to Data Portability								
Right to object to Automated Decision-Making							✓	
Right to Withdraw Consent								
Right to Complain								
Right ... not to be Discriminated								

End of Table

With regard to the correlation of the CPLF and PbD guidelines by O’Leary [13], Table 6 shows that O’Leary’s guidelines cover most of the principles and rights of the CPLF. Considering the right of the CPLF, as seen in Table 6, all the rights of the CPLF are achieved by O’Leary [13] except the – **Right to Data Portability, Right to Withdraw Consent, Right to Complain, and Right of Individuals not to be Discriminated.** According to the principles of the CPLF, O’Leary’s [13] guidelines cover many of these principles: –**Transparency, Purpose Limitation, Limiting Use and Disclosure, Data Minimisation, Lawfulness of processing, Accuracy, Storage Limitation, Security, and Accountability.**

-- Begin of Table

Table 7. Mapping between the Combined Privacy Laws Framework and Privacy by Design Guidelines (Perera et al. 2019) (shortened form of the terminologies; see Section 4 for the full form of the CPLF)

Guidelines	Guidelines by Perera et al. (2019) [44]																														
<b>Privacy Laws/ Rights</b>	01. Minimise data acquisition	02. Minimise number of ...	03. Minimise raw data ...	04. Minimise knowledge ...	05. Minimise data storage	06. Minimise data retention ...	07. Hidden data routing	08. Data anonymisation	09. Encrypted data communication	10. Encrypted data processing	11. Encrypted data storage	12. Reduce data granularity	13. Query answering	14. Repeated query blocking	15. Distributed data processing	16. Distributed data storage	17. Knowledge discovery based ...	18. Geography based aggregation	19. Chain aggregation	20. Time-Period based ...	21. Category based aggregation	22. Information Disclosure	23. Control	24. Logging	25. Auditing	26. Open Source	27. Data Flow	28. Certification	29. Standardisation	30. Compliance	
Transparency																															
Purpose Limitation			✓																												
Limiting Use ..		✓	✓								✓	✓					✓		✓	✓	✓										
Data Min- imisation	✓	✓	✓		✓						✓	✓					✓	✓	✓		✓										
Consent																															
Lawfulness of Processing																															
Accuracy																															
Storage Limitation		✓			✓																										
Security						✓		✓	✓	✓				✓	✓	✓			✓												
Accountability																								✓	✓	✓	✓	✓	✓	✓	✓
Anonymity and Pseudonymity							✓																								
Source																															
Cross- border Disclosure																															
..																															



-- Continuation of Table

Guidelines	Guidelines by Perera et al. (2019) [44]																															
<b>Privacy Laws/ Rights</b>	01. Minimise data acquisition	02. Minimise number of ...	03. Minimise raw data ...	04. Minimise knowledge ...	05. Minimise data storage	06. Minimise data retention ...	07. Hidden data routing	08. Data anonymisation	09. Encrypted data communication	10. Encrypted data processing	11. Encrypted data storage	12. Reduce data granularity	13. Query answering	14. Repeated query blocking	15. Distributed data processing	16. Distributed data storage	17. Knowledge discovery based ...	18. Geography based aggregation	19. Chain aggregation	20. Time-Period based ...	21. Category based aggregation	22. Information Disclosure	23. Control	24. Logging	25. Auditing	26. Open Source	27. Data Flow	28. Certification	29. Standardisation	30. Compliance		
Dealing with Unsolicited Data																																
Adoption ... an identifier																																
Right ... to exercise their rights																							✓									
Right to be informed																						✓										
Right of Individuals Access																							✓									
Right to Rectification																							✓									
Right to Erasure																							✓									
Right to Restriction ...																							✓									
Right to Object																							✓									
Right to Object to Marketing																							✓									
Right to Data Portability																							✓									
Right to ... Automated ...																							✓									
Right to Withdraw Consent																																
Right to Complain																																
Right .. Discriminated																																

End of Table

Table 7 shows the correlation between the Privacy by Design (PbD) guidelines by Perera et al. [44] and the CPLF. These 30 guidelines are inspired by Hoepman’s strategies and have been developed for the IoT domain specifically to help software engineers develop and assess IoT applications [44]. As seen in Table 7, various principles and rights of the CPLF are achieved by Perera et al.’s [44] guidelines. Nevertheless, these guidelines tend to focus on achieving some of the CPLF’s principles through several of the guidelines, rather than covering all the principles of the CPLF. For example, the – **Data Minimisation** – principle of the CPLF is covered by ten of Perera et al.’s [44] guidelines, while the – **Transparency**– principle is not covered by any of these guidelines. With regards to the rights of the CPLF, interestingly, all of these rights are covered by Perera et al.’s [44] guidelines except, **Right to Withdraw Consent**, **Right to Complain**, and **Right of Individuals not to be Discriminated**.

### 6.3 Mapping Privacy Laws and Privacy Patterns

This section correlates the privacy patterns and the principles and rights of the CPLF. These privacy patterns are gathered from [47, 48], as many common patterns are shared between these two resources. The principles and the rights of the CPLF are usually aimed at the legal domain and not the technical domain due to remaining disconnected from developers’ tools and the environment required for building applications. Therefore, mapping the principles and the rights of the CPLF with the privacy patterns is essential to facilitate developers building a privacy-aware application and complying with the law. Typically, patterns are more reliable and it is possible to explain their use in a particular context, compared to guidelines, strategies or principles for PbD schemes, which is highlighted in Table 3, Table 4, Table 5, Table 6, and Table 7. The following criteria are followed in order to map between the privacy laws and the privacy patterns:

- Direct relationship: If a specific pattern can achieve a law (principle/right) directly (a direct law).
- Indirect relationship: If a specific law can achieve a specific pattern through a direct law.

Table 8. Mapping between the Combined Privacy Laws Framework and Privacy by Design Patterns (*shortened form of the terminologies; see Appendix C Section C.4 for the full form of privacy patterns and Section 4 for the full form of the CPLF*)

-- Begin of Table

Privacy Patterns	Transparency	Purpose Limitation	Limiting Use and Disclosure	Data Minimisation	Consent	Lawfulness of Processing	Accuracy	Storage Limitation	Security	Accountability	Anonymity and Pseudonymity	Source	Cross-border Disclosure ...	Dealing with Unsolicited Data	Adoption ... an identifier	Right ... to exercise their rights	Right to be informed	Right of Individuals Access	Right to Rectification	Right to Erasure	Right to Restriction ...	Right to Object	Right to Object to Marketing	Right to Data Portability	Right to object to Automated ...	Right to Withdraw Consent	Right to Complain	Right ... not to be Discriminated
1. Protection against ...		◦						•	◦	◦	•																	
2. Location Granularity		◦	•	•						◦																		
3. Minimal Information ...	•	◦		•						◦							•											
4. Informed Secure Passwords									•	◦																		
5. Awareness Feed	•									◦							•											
6. Encryption ...									•	◦																		
7. Federated Privacy ...										•																		
8. Use of Dummies									◦	◦	•																	
9. Who’s Listening										◦							•											

-- Continuation of Table

Privacy Patterns	Transparency	Purpose Limitation	Limiting Use and Disclosure	Data minimisation	Consent	Lawfulness of Processing	Accuracy	Storage Limitation	Security	Accountability	Anonymity and Pseudonymity	Source	Cross-border Disclosure ...	Dealing with Unsolicited Data	Adoption ... an identifier	Right ... to exercise their rights	Right to be informed	Right of Individuals Access	Right to Rectification	Right to Erasure	Right to Restriction ...	Right to Object	Right to Object to Marketing	Right to Data Portability	Right to object to Automated ...	Right to Withdraw Consent	Right to Complain	Right ... not to be Discriminated
10. Privacy Policy Display	●									○							●											
11. Layered Policy Design	●									○							●											
12. Discouraging Blanket ...																												
13. Reciprocity																												
14. Asynchronous Notice										○							●											
15. Abridged Terms ...	●									○						●												
16. Policy Matching Display																												
17. Incentivized Participation																												
18. Outsourcing [with consent]		○	●	●	●					○																		
19. Ambient Notice	●									○							●											
20. Dynamic Privacy Policy ...	●									○							●											
21. Privacy Labels	●									○							●											
22. Data Breach Notification ...								●	●																			
23. Pseudonymous Messaging								●	○	●																		
24. Onion Routing								●	○	●																		
25. Strip Invisible Metadata		○	●	●						○																		
26. Pseudonymous Identity										○	○	●																
27. Personal Data Store																												
28. Trust Evaluation ...	●									●							●											
29. Aggregation Gateway				○				●	○																			
30. Privacy icons	●									○							●											
31. Privacy-Aware Network ...	●									○							●											
32. Sign an Agreement ...					●	●				○																		
33. Single Point of ...								●	○																			
34. Informed Implicit ...	●				●	○				○							●											
35. Enable/Disable Function	●				●	○				○							●											
36. Privacy Color Coding	●									○							●											
37. Appropriate Privacy Icons	●									○							●											
38. User Data Confinement ...		○	●							○																		
39. Icons for Privacy Policies	●									○							●											
40. Obtaining Explicit Consent					●	●				○																		

-- Continuation of Table

Privacy Patterns	Transparency	Purpose Limitation	Limiting Use and Disclosure	Data minimisation	Consent	Lawfulness of Processing	Accuracy	Storage Limitation	Security	Accountability	Anonymity and Pseudonymity	Source	Cross-border Disclosure ...	Dealing with Unsolicited Data	Adoption ... an identifier	Right ... to exercise their rights	Right to be informed	Right of Individuals Access	Right to Rectification	Right to Erasure	Right to Restriction ...	Right to Object	Right to Object to Marketing	Right to Data Portability	Right to object to Automated ...	Right to Withdraw Consent	Right to Complain	Right ... not to be Discriminated
41. Privacy Mirrors										o							•	•										
42. Appropriate Privacy ...	•									o							•	•										
43. Impactful Information ...										o							•	•										
44. Decoupling [content] ...								•	o																			
45. Platform for Privacy ...	•									o							•	•										
46. Selective Access								•	o																			
47. Pay Back										o																		
48. Privacy Dashboard	•									o						•	•	•	•	•	•	•	•	•	•	•	•	•
49. Preventing Mistakes ...		o	•		o	o				o							•	•										
50. Obligation Management		o	•					•		•							•	•										
51. Informed Credential ...	•	o	•							o							•	•										
52. Anonymous Reputation ...								•	o	•																		
53. Negotiation of ... Policy																												
54. Reasonable Level of ...		o	•							o																		
55. Masquerade		o	•							o																		
56. Buddy List		o	•							o																		
57. Privacy Awareness Panel	•									o							•	•										
58. Lawful Consent		•			•	•				o																		
59. Privacy Aware Wording	•									o										o								
60. Sticky Policies		o	•					•		•							•	•										
61. Personal Data Table	•									o							•	•										
62. Informed Consent ...					•	•				o																		
63. Added-noise ...		o	•							o																		
64. Increasing Awareness ...	•				o					o							•	•										
65. Attribute Based ...		o	•							o	o	•																
66. Trustworthy Privacy ...		o	•																									
67. [Support] Selective ...		o	•	•						o	o	•																
68. Private Link		o	•							o																		
69. Anonymity Set										o	o	•																
70. Active Broadcast of ...		o	•	•	o					o																		

-- Continuation of Table

Privacy Patterns	Transparency	Purpose Limitation	Limiting Use and Disclosure	Data minimisation	Consent	Lawfulness of Processing	Accuracy	Storage Limitation	Security	Accountability	Anonymity and Pseudonymity	Source	Cross-border Disclosure ...	Dealing with Unsolicited Data	Adoption ... an identifier	Right ... to exercise their rights	Right to be informed	Right of Individuals Access	Right to Rectification	Right to Erasure	Right to Restriction ...	Right to Object	Right to Object to Marketing	Right to Data Portability	Right to object to Automated ...	Right to Withdraw Consent	Right to Complain	Right ... not to be Discriminated
71. Unusual Activities									●	○							●											
72. Identity Federation ...										●																		
73. Dynamic Location ...		○	●					○	○	●																		

End of Table

In the initial move towards correlating the privacy patterns and the CPLF, it is useful to construct criteria showing the capability of the privacy patterns to apply various principles and rights of the CPLF. Table 6 aims at correlating the privacy patterns and the principles and rights of the CPLF, which will enable thorough and efficient compliance with the main principles and rights of the CPLF of the various data protection laws. Two criteria have been identified: the (●) in the various cells determines a direct relationship, and the (○) shows an indirect relationship between the privacy patterns and the CPLF. Underlining the relationship between the privacy patterns and among the various principles and rights of privacy laws, the criteria indicates that most of the privacy patterns are associated with more than one principle or right, except the following patterns: **Discouraging Blanket Strategies, Reciprocity, Policy Matching Display, Incentivised Participation, Personal Data Store, Pay Back, and Negotiation of Privacy Policy.** This might be due to the nature of the privacy patterns as they are more specific than the principles or rights of the CPLF. Nevertheless, some of the principles and rights of the CPLF have not been associated with any of the privacy patterns, as seen in Table 6. These are the following principles: **Source, Cross-border Disclosure of Personal Data, Dealing with Unsolicited Data, and Adoption, Use or Disclosure of an identifier.** However, these principles of the CPLF are only limited to Australia's and New Zealand's data protection laws. With Regard to the rights of the CPLF, **Right to Data Portability, Right to Complain, and Right of Individuals not to be Discriminated** are not achieved by any of the privacy patterns. This could be due to the nature of the law as being largely disconnected from the technical domain. Some of the provisions of laws, furthermore, require organisations to comply with the provisions rather than implementing them in the development phase. Therefore, it cannot be implemented in the technical domain.

### 7 INTERNET OF THINGS ARCHITECTURE

This section briefly presents an overview of the IoT in general and its architecture, and demonstrates how to apply and map privacy patterns to IoT architectures at the design stage. The Internet of Things (IoT) may be described as a collection of physical objects or 'things' that are interconnected and have abilities involving computing, and sensing and actuation, along with being able to communicate with each other and different systems in order to exchange information and collect data [46, 50]. Designing and developing processes for IoT applications is more complex than for desktop, mobile or web applications due to several reasons. Firstly, for IoT applications, it is necessary to have both software and hardware, such as sensors and actuators, which can work together across various types of nodes. These include system-on-chips, mobile phones, and cloud platforms, which have a range of capabilities according to the specific condition [45]. Secondly, developing IoT applications requires different software engineering experts, for example, desktop, mobile or web, to work together. This leads to a complex situation as the different software engineering specialists collaborate in order to combine the various types of hardware and software necessary. Moreover, the situation is yet more difficult due to a lack of integrated development stacks for supporting the engineering of end-to-end IoT applications.

## 7.1 Overview of the Internet of Things (IoT) Software Architecture

Data is typically moved from sensing devices to gateway devices, and to the cloud infrastructure in IoT applications [45], which is the most commonly used architectural pattern for IoT application development; it is known as a centralised architecture pattern [52]. This pattern is usually made up of three components, which are IoT devices; gateway devices, and IoT cloud platforms (see Figure 3), and these all differ in their computational capabilities. An IoT application usually integrates the various types of devices with their different capabilities [17, 44]. It should also be borne in mind that each requires specific privacy protection measures to be taken into account according to their individual characteristics.

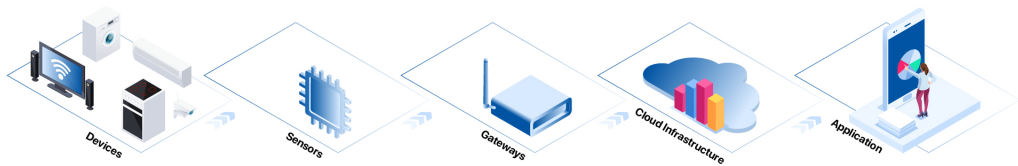


Fig. 3. Data Flow of IoT Architecture

The five phases of the data lifecycle is defined as ensuring a systematic approach to thinking about the data flow for the application of our PbD framework within an IoT system. In all of the devices, or nodes, the data passes through five data life cycle phases, which are: Consent and Data Acquisition (CDA), Data Preprocessing (DPP), Data Processing and Analysis (DPA), Data Storage (DS) and Data Dissemination (DD). The CDA phase consists of routing and data collection activities performed by a specific node. DPP refers to any type of processing of raw data in preparation for it being used with a different processing procedure [64]. In general, DPA involves collecting and manipulating data items to attain meaningful information [59]. DD refers to distributing or transmitting data to an external party. These life cycle phases of the data are applicable to all of the nodes contained in an IoT application, and they allow software engineers to implement the mechanisms necessary to protect users' privacy. Even so, due to the decision of the engineers, certain data lifecycle phases in some nodes are not always utilised, for example, a sensor node may simply be used in the DPP phase for averaging out temperature data. This may be followed by either the DPA or DS phases involving analysing or storing the data, and because of hardware and energy constraints, the sensor node can push the data that has been averaged to the gateway node through the DD phase.

## 7.2 Example of IoT scenarios

In this section, two case scenarios are presented at a high level, which will be used later on to highlight the privacy challenges and to demonstrate how to apply various privacy patterns to the data flow of the IoT architecture. As stated previously, privacy patterns are more concrete compared to principles, strategies, and guidelines. This allows consideration of the perspective of the owner with the problem, with the opportunity for each problem to be solved through the development of an IoT application.

**7.2.1 Use Case 1: Car Finder.** This use case is inspired by 'Carfinder' project which has been designed and implemented by IBM® and IBM Business BM Business Partner Zebra Technologies in cooperation with AUDI, as a solution for vehicle tracking in real time [62].

**Summary of the Use Case:** People often park their car in different places and can forget where they parked it and may even have no idea where to even begin to finding it. IoT provides a good solution to help people easily find their car. As shown in Figure 4, the car is equipped with a sensor that reports a GPS location. There is also an IoT gateway inside the car, which is operated by the car company and is capable of communicating with the sensor via Bluetooth. Once a person parks his/her car, the gateway sends the car's location, which is reported by the sensor to the cloud through an Internet connection to store the location of

the car. Once the person needs to know his/her car location, he/she can easily access their mobile application and request the car location through a WiFi or mobile connection, and in turn, the car's location will be retrieved from the cloud. In addition, the mobile application analyses the collected car's locations for future suggestions.

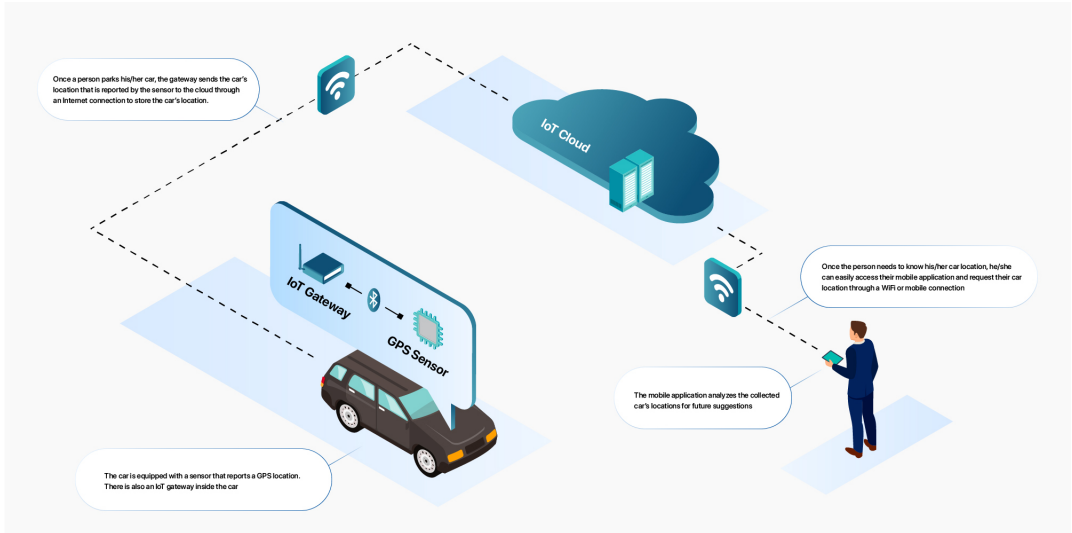


Fig. 4. Use Case 1: Car Finder

**7.2.2 Use Case 2: Gym Monitoring System.** This use case is inspired by smartwatches available in the market.

**Summary of the Use Case:** Sara is a trainer in a gym who faces difficulties in managing the high number of participants in the gym at the same time. Smart Gym is a helpful IoT solution that facilitates trainers managing gym participants and monitoring their progress easily. As shown in Figure 5, within the gym there are three different use cases: (1) some participants only use an Apple watch, (2) some participants use an Apple watch together with a Heart Rate monitor chest strap, and (3) other participants use a Samsung watch. As stated previously in Section 7.1, different nodes do different kinds of processing based on their capabilities. Gym Activity is a third-party application that can be used by the participants and a trainer in the gym to monitor their activities. Accordingly, each use case has its own flow as follows:

- (1) **Apple Watch Use Case:** Each participant wears an Apple watch that includes multiple sensors (e.g., heart rate monitor, GPS, accelerometer) to collect data. These collected data are used to monitor activities, such as how many steps taken, the distance covered, the calories burned, and what the person's heart rate is. Once a participant starts a workout, the Gym Activity application sends a notification via Bluetooth to the trainer which informs her that the participant has started the workout. The trainer, accordingly, can reply with a motivational message to the participant. While the participant starts a workout, the sensor displays a real-time heart rate, the active calories, the distance covered and the total time, in the Gym Activity application. In case a participant has an emergency situation, an alert is sent to the trainer's mobile application. Once a participant has completed the workout, the Gym Activity application transfers the average heart rate collected and the average calories burned through Wi-Fi to the local server at the gym, as demonstrated in Figure 5. Simultaneously, the Gym Activity application sends a notification to the trainer to inform her that a participant has completed the workout, along with a summary of the workout: the total time, the total calories, and the average heart rate.

- (2) **Apple Watch together with the Chest Strap Use Case:** In this case, each participant wears an Apple watch together with the Polar H7/H10 heart rate sensor with a chest strap for those who prefer an additional layer of accuracy. Apple watch has the ability to pair with Polar H7/H10 heart rate sensor. Therefore, the participants have to pair the Apple Watch with the chest strap device via Bluetooth in order to synchronize the Heart Rate data to the Gym Activity application and modify the required settings in the application. The complete case would be the same as the previous case.
- (3) **Samsung Watch Use Case (Old Version):** Each participant wears a Samsung Watch that includes multiple sensors (e.g., heart rate monitor, GPS, accelerometer) to collect data. These collected data are used to monitor activities, as stated previously. In this case, participants have to use their mobile phone together with the Samsung Watch in order to obtain accurate readings, since the Samsung Watch does not have the capabilities to perform accurate processing. Once a participant starts a workout, the Gym Activity application on the mobile phone sends a notification via Bluetooth to the trainer which informs her that the participant has started the workout. The trainer, accordingly, can reply with a motivational message to the participant. While the participant starts a workout, the Android Watch sensor displays the real-time heart rate, the active calories, the distance covered, and the total time. Simultaneously, the Android Watch pushes the real-time data to the Gym Activity application via Bluetooth, since it does not have the capability to do the processing of these collected data. In case a participant has an emergency situation, an alert is sent to the trainer's mobile application. Once a participant has completed the workout, the Gym Activity application on the mobile phone transfers the collected average heart rate, and the average calories burned, through Wi-Fi to the local server at the gym, as shown in Figure 5. At the same time, it sends a notification to the trainer to inform her that a participant has completed the workout with a summary of the workout: the total time, the total calories, and the average heart rate.

In all these three cases, the Gym Activity application allows the participant to create an account and enter their name, weight, height and age. It also allows participants to display the following information: average heart rate, active calories, and the distances covered. In addition, the participant can present visualised data from previous workout history that displays the statistics of the total calorie losses, and the average heart rate since the participant started. Gym participants can, furthermore, share their workout statistics, their progress of losing weight, and pictures of their body to encourage their friends in the gym. In order for the trainer to improve their participant's progress, the trainer could do advanced analysis on the cloud of their participant's data and suggest different plans for the workout in order to improve their progress, or they could store the workouts in the cloud for archiving purposes.

### 7.3 Mapping Privacy Patterns to IoT architecture

A major problem is that the owner typically focuses on the requirements that would help to address their problem [7] without consideration of privacy issues. Hence, privacy requirements are often overlooked during the design of software architectures for IoT applications. This section aims at guiding developers by demonstrating how to apply the privacy patterns to IoT architecture for the two IoT scenarios presented in Section 7.2.

While these devices bring about new services, increase convenience, and improve efficiency, they also bring privacy and security risks.

**7.3.1 Mapping Privacy Patterns to the Car Finder Use Case.** As this IoT solution collects the user's location, which could identify the user and cause a risk to the user's privacy, it is imperative to apply the privacy patterns to the flow of data, not only to protect user's privacy, but also to comply with the data protection law. To highlight the way this may work in reality, the next section will examine the previous scenario presented in Section 7.2.2 and apply privacy patterns for developing a privacy-aware IoT application.

It is important to note that different types of privacy protecting measures can be taken for each of these different components based on their characteristics. Applying various privacy patterns would facilitate developers complying with the data protection laws. As shown in Section 6.3 in Table 8, when developers apply a specific pattern, it automatically complies with some of the principles or rights of the data protection laws, as demonstrated in Table 8. As shown in Figure 6, when the user receives the car location, the route the



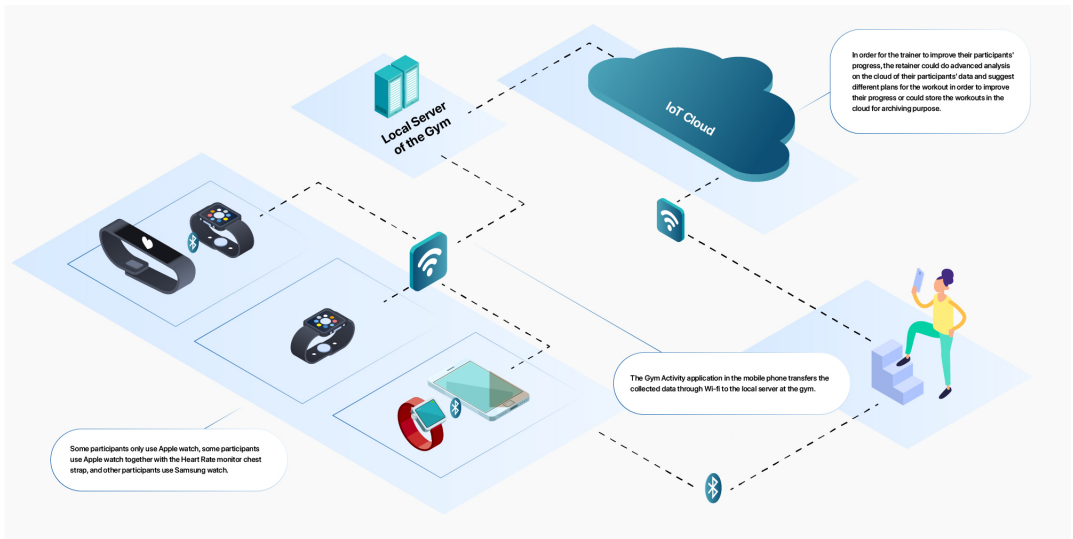


Fig. 5. Use Case 2: Gym Monitoring System

data travels is complex as it needs to go through different nodes before reaching its final destination. Taking into consideration the privacy requirements at each element of IoT architecture would help developers to build a privacy-aware IoT application.

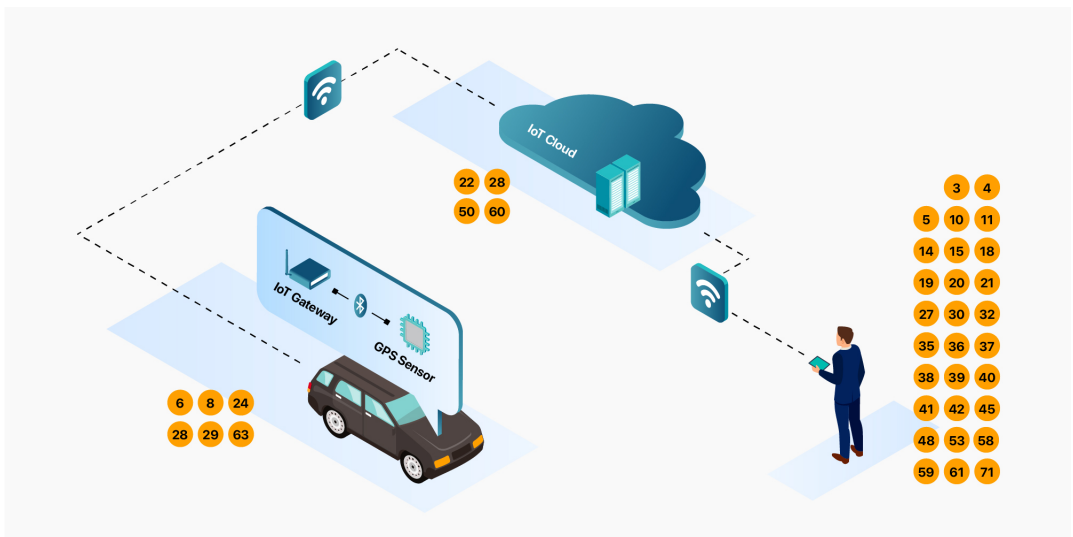


Fig. 6. Applying Privacy Pattern to the Car Finder Use Case

(1) **Applying Privacy Patterns to the IoT Gateway:**

When the IoT gateway receives the car location from the GPS sensor, privacy pattern number 6 – **Encryption with a User-managed Key** – ensures personal information that could be transferred or stored by an untrustworthy third party is kept confidential. As data is routed between different nodes, applying pattern 24 – **Onion Routing** – to the data would encapsulate the data within a number of

layers of encryption, thereby limiting the amount of knowledge in each node located along the delivery path. This, in turn, would help developers to comply directly with the security principles of the CPLF. In addition, since the exact location of the car should be stored, it is worth applying pattern 8 – **Use of Dummies** –, which simultaneously adds fake locations in such a way that the third party is unable to distinguish fake from real information. Accordingly, applying these privacy patterns would help developers to directly comply with the Security and Anonymity and Pseudonymity principles of the CPLF. According to pattern 28 – **Trust Evaluation of Services Slides** –, it is important for the user to trust the service does not negatively impact their particular privacy requirements. Hence, a trust evaluation function needs to be used that is in accordance with relevant parameters for measuring how trustworthy communication partners are and to establish their reliability. Accordingly, it helps developers to directly adhere to the Transparency and Accountability principles of the CPLF and granting users the Right to be Informed. As a third party aims to meet the operating requirements, it is important to apply privacy pattern 29 – **Aggregation Gateway** – which uses homomorphic encryption by using a secret question and answer shared only with the third party that is working on enhancing the system. This third-party will not know what the content is due to it being encrypted, yet it can still work on that data in an encrypted format because the encryption system is homomorphic. This encryption prevents any revealing of the user's information, such as the user's habits in this scenario as it collects the car's location. By applying this pattern, the service provider would comply with the security principle of the CPLF directly.

In order to avoid any exploitation of information that could infer sensitive user information, applying privacy pattern 63 – **Added-noise Measurement Obfuscation** – is necessary to avoid this privacy issue. As this pattern seeks to add some noise to the service operation, for example, storing fake parking locations, no extra personal information may be inferred based on the aggregation of the user's information, such as what time they leave or return home. This would result in complying with the principle of Limiting Use and Disclosure of the CPLF directly.

(2) **Applying Privacy Patterns to the IoT Cloud:**

As this IoT scenario requires storing the car's location for the user, which could cause a risk to the user's privacy when any data breach occurs, it is crucial to apply privacy pattern 22 – **Data Breach Notification Pattern** –, to detect and react to a data breach quickly, since it could identify users' locations. This, in turn, would help developers in complying with the Security and Accountability principles of the CPLF. As pattern 28 – **Trust Evaluation of Services Slides** – could be applied to the IoT gateway, it is also applicable to the IoT cloud to ensure that the user trusts the service, and to verify that a service does not undermine their personal privacy requirements. Accordingly, the Transparency and Accountability principles of the CPLF are satisfied, as well as the Right to be Informed being achieved by applying this privacy pattern.

Since the data could be access or handled by a third party (the IoT cloud in this scenario), the controller could share the data in ways that may not be approved by the participants. Therefore, applying privacy pattern 50 – **Obligation Management** – facilitates obligations around data sharing, storing and processing to be managed, and responsibilities can be altered if the data is shared among numerous parties. In this scenario, applying this pattern is helpful to ensure that the third party is aware of and complies with the policies required by the user or organisational policies. Accordingly, developers would adhere directly with the principles of the Data Minimisation, Storage Limitation, and Accountability. It also helps developers to grant participants the Right to be Informed. This is similar to the privacy pattern 60 – **Sticky Policy**.

(3) **Applying Privacy Patterns to the Mobile Application:**

The controller of the mobile application has to maintain privacy policies as they are an essential aspect that involves data subjects, users, and aspects of processing; furthermore, it is crucial to follow the laws that stipulate those policies. Privacy patterns **10, 11, 15, 20, 21, 30, 36, 37, 39, 45 and 59** all focus on solving privacy issues in regard to privacy policies. Since privacy policies usually tend to be complex and long, these privacy patterns are concerned about balancing these policies with regard to accessibility, alongside being comprehensive from a legal perspective. Moreover, these patterns seek to present privacy policies in a clear way to ensure that users are clearly informed about the processing of

their personal information. For example, Pattern 11 – **Layered Policy Design** – requires policies to be summarised in a nested way, so users are able to understand what they should expect from dealings with their personal data by a data controller with regard to the terms on which data is managed and to address specific purposes. Accordingly, applying these privacy patterns will help developers to directly adhere to the Transparency principle of the CPLF, as well as the Right to be Informed.

Regarding the personal data of the user, the mobile application should not collect any other information about the user that does not contribute to achieving the specified purpose. This applies to pattern 3 – **Minimal Information Asymmetry**. In this scenario, the objective is to find the car's location, so based on this pattern developers must not acquire any other types of data to include in the application. This will reduce the risk to the user's personal data and will help developers to not only comply with the Data Minimisation principle of the CPLF, but also adhere to the Transparency principle. Furthermore, applying this pattern will grant participants the Right to be Informed, as acquiring minimal information from users would reduce the issue of imbalance within the field of policy knowledge, including the knowledge held by the user regarding the controller and its practices.

As users of the mobile application may not be equipped to maintain strong passwords, remember them and protect them, privacy pattern 4 – **Informed Secure Passwords** – requires controllers to provide users with assistance in understanding and maintaining strong passwords that are easier to remember. This would result in complying with the Security principle of the CPLF directly, and the Accountability principle of the law indirectly. In a similar context, pattern 71 – **Unusual Activity** – asks controllers to alert users of unauthorised access in order to protect users. This would result in complying directly with the Security principle and would grant individuals the Right to be Informed. It also helps developers to comply with the Accountability principle indirectly.

Users are typically unaware of the risks to privacy from their data sharing activities, especially when those risks are either indirect or long term risks. Privacy pattern 5 – **Awareness Feed** – makes users more aware of these risks through requesting that the controller informs the user prior to starting the application processes about car collection locations. Users should be informed before processing personal data and should be given a warning about possible negative consequences at a time that is early enough to be taken note of, while late enough to still be relevant. In a similar fashion, pattern 19 – **Ambient Notice** –, requires the controller to present a succinct yet clear notification as the GPS sensor collects their car's locations, which does not interrupt the user's activity. Similarly, pattern 42 – **Appropriate Privacy Feedback** – requires the controller to provide clear feedback loops that gain the user's attention in order to make sure that the user understands whenever a new car's location is collected, and they can view that data and its possible uses. By applying these patterns, developers would comply directly with a principle and a right of the CPLF, Transparency, and the Right to be Informed respectively, as well as adhering to the Accountability principle indirectly. Like pattern 14 – **Asynchronous Notice** –, it asks the controller to provide a simple reminder that they have consented to the sensor to collect their car's location and users could configure the settings if they do not want to see this reminder again. Applying this pattern would help developers to comply with one right of the CPLF - the Right to be Informed. It also helps developers to adhere to the Accountability principle indirectly.

As demonstrated in Figure 6, the IoT gateway sends the car's location to the IoT cloud, which could be managed by a third party. Therefore, applying privacy pattern 18 – **Outsourcing [with consent]** – is essential before allowing the third party to process their data. Applying this pattern helps developers to comply with three principles of the CPLF directly: the Limiting Use and Disclosure principle, the Consent principle, and the Lawfulness of Processing principle. It also adheres to two principles of the CPLF indirectly: the Accountability principle, and the Purpose Limitation principle, where it should specify the purpose to limit the use and disclosure of the data collected for that purpose. Similarly, pattern 32 – **Sign an Agreement to Solve Lack on a Use of Private Data Context** – involves the controller providing the user with a contractual agreement so that they are more obligated to stick to their word. Like pattern 40 – **Obtaining Explicit Consent** – which requires controllers to obtain unambiguous consent from their users in order to collect and store their cars' locations, either by using contractual consent, or by signifying their consent, such as using a button, where users could click 'I

consent.' Applying patterns 32 and 40 will result in complying directly with the Consent principle, and Lawfulness of Processing and the Accountability principle indirectly. Similarly, pattern 58 – **Lawful Consent** – addresses the legal and social obligations involved when the data subject provides consent for their data to be processed, under specific circumstances, in enough detail. This consent of the user should be purpose-separated so that users have to give consent for the collection of the car's location and consent for storing data for further analysis. This would result in complying directly with the Purpose Limitation, consent, and Lawfulness of Processing principles.

Regarding users' preferences, Pattern 53 – **Negotiation of Privacy Policy** – asks the controller to determine their users' privacy preference, and if the user's preference is unknown, they should use the highest level of privacy settings. In this scenario, the controller stores the car's location by default all the time unless he/she chooses 'No' or vice versa. Nevertheless, none of the principles and rights of the CPLF are suited to this privacy pattern. Pattern 35 – **Enable/Disable Function** – requires the controller to allow users to enable and disable any functions, such as disable the sensor which takes the car's location, or disable the function which stores the car's locations to process and analyse them for future suggestions. When developers apply this pattern, they would directly comply with the Consent and the Transparency principles of the CPLF, and this would help developers to grant individuals the Right to be Informed; they will also be adhering to the Accountability and the Lawfulness of processing principles indirectly. This avoids the need to trust service providers to collect personal data by storing the car's location in the mobile application instead of storing data in the IoT cloud. This applies privacy pattern 38 – **User Data Confinement Pattern** – which could be used if collecting personal data for a specific but legitimate purpose that holds a level of risk to the privacy of the user, accordingly, it complies with the Data Minimisation principle of CPLF directly. In a similar fashion, privacy pattern 27 – **Personal Data Store** – improves the amount of control the user has over their personal data by storing their data in a personal storage location (mobile) so the user can decide whether to share their data with a third party who could manage the IoT cloud. This, however, has not achieved any of the principles and rights of the CPLF. With regard to the processing of the collected car's location, pattern 61 – **Personal Data Table** – tracks the processing of the cars' locations to enable the user to view the activities related to their data for the purposes of suggesting parking locations in the future, and they can easily review their preferences. This would result in complying with the Transparency principle of the CPLF and granting users the Right of Individuals Access, and the Right of the Individual to Exercise their Rights.

Pattern 41 – **Privacy Mirrors** – addresses the socio-technical domain by suggesting methods, mechanisms, and interfaces which can show the history, flow, state, and nature of the personal data processed which would have otherwise been hidden. In this scenario, the controller should provide the user with access to the data collected about the car's locations, as well as the processing operations concerning their data. This would help developers to comply with the law by granting individuals the Right to be Informed and the Right to Individuals Access. Pattern 48 – **Privacy Dashboard** – is wider as it does not only grant access to the user, but it also allows them to easily control their data themselves and related permissions; that is, by amending, erasing, or modifying the purposes they can be used for, or indeed, those whom the data is allowed to be shared with if this applies. By applying this pattern, developers would be complying with most of the rights of the CPLF: the Right of Individuals to Exercises their Rights, the Right to be Informed, Right to Individuals Access, the Right to Rectification, the Right to Erase, the Right to Restriction of Processing, the Right to Object, the Right to Object to Marketing, the Right to Object to Automated Decision-making, and the Right to Withdraw Consent. This would also help them to adhere indirectly to the Accountability principles.

**7.3.2 Mapping Privacy Patterns to the Gym Monitoring System Use Case.** As this IoT solution collects personal information that could cause a risk to the user's privacy, the privacy patterns will be applied to the data flow to protect users' privacy and to comply with the data protection law. To highlight the potential of this, the scenario presented in 7.2.2 will be revisited and the privacy patterns will be applied to developing a privacy-aware IoT application.

**(1) Applying Privacy Patterns to the Gym Activity Application:**

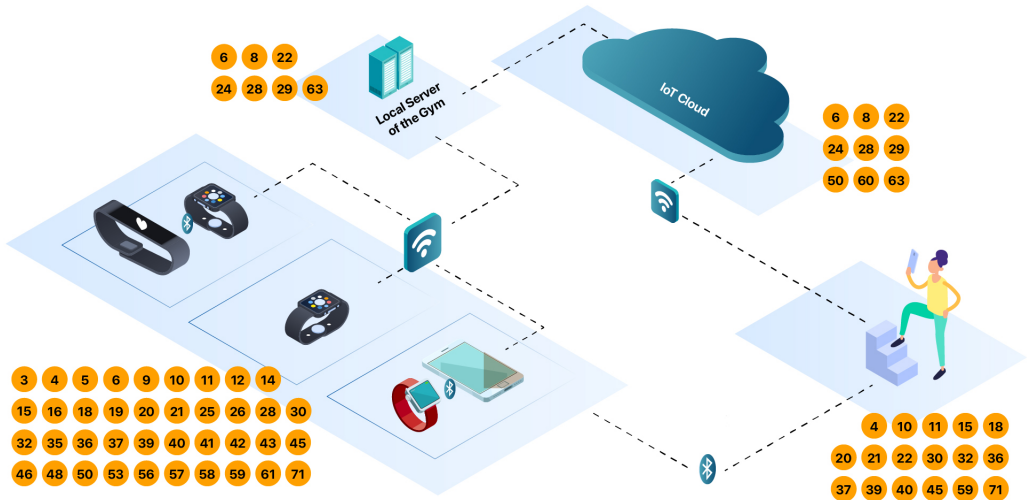


Fig. 7. Applying Privacy Patterns to the Gym Monitoring System

As demonstrated in Figure 7, when a participant starts the workout, the sensor starts collecting different types of data in real-time. The data collected are heart rate, speed, distance and accelerometer, which is used to derive the participant’s activity, while the heart rate, distance, and speed could be used to derive the calories burned. Based on this scenario, developers can decide not to acquire any other data that is not used to achieve the objective of this application. This is achieved by privacy pattern 3 – **Minimal Information Asymmetry** – which not only seeks to minimise data, but also contributes to reducing the imbalance of policy knowledge, where users will be more aware of the controller’s practices when controllers acquire less information about them. This would help developers to comply directly with the Data Minimisation and Transparency principles and granting participants the Right to be Informed. As the users of the Gym Activity application may not be equipped to maintain strong passwords, remember them and protect them, privacy pattern 4 – **Informed Secure Passwords** – requires controllers to assist users in understanding and maintaining strong passwords that they can easily recall. This would result in complying with the Security principle of the CPLF directly, and the Accountability principle indirectly. However, in the case of unauthorised access, it is crucial to alert the participant and trainer to protect their personal data. This applies pattern 71 – **Unusual Activity** – which would result in complying directly with the Security principle and granting users the Right to be Informed. It also helps developers to comply with the accountability principle indirectly.

Users are typically not aware of the privacy risks presented by data sharing activities, in particular, if they are indirect risks or long-term risks. Accordingly, developers have to inform the users of the Gym Activity application and the possible consequences in a timely manner prior to implementing the application and gathering their personal data, or if there is a risk of personal data being affected if it is not early enough to be appreciated or too late to be relevant. This reaches privacy pattern 5 – **Awareness Feed**. Like pattern 19 – **Ambient Notice** – which requires the controller to make an unobtrusive but clearly visible notification available at the point when the sensors start collecting their data. Similarly, pattern 42 – **Appropriate Privacy Feedback** – requires the controller to provide feedback loops that are visible and made aware to the user. Accordingly, the user is aware whenever sensors start collecting data, how that data could be used (the trainer), and who is able to see the data (the trainer and the others who the data is shared with). When applying these patterns, the developer would directly adhere to the Transparency principle of the CPLF and grant participants the Right to be Informed. In addition, they would comply with the Accountability principle indirectly. In a similar

fashion, pattern 14 – **Asynchronous Notice** – requests that the controller provides a clear basic reminder that they have given consent to the sensors to collect their data, and that users can configure the settings in the event that they do not want the reminder to appear again. This would result in complying directly with part of the CPLF by granting participants the Right to be Informed. It would also help developers in complying with the Accountability principle indirectly.

As participants can share their progress with other participants, it is essential to protect the user's information by informing the participants that their access is not being made private, and to tell them about other users, including possible unauthenticated ones, who can also access the content. This achieves privacy pattern 9 – **Who's Listening** – which helps developers to comply with part of the CPLF as they directly grant participants the Right to be Informed. In a similar fashion, pattern 57 – **Privacy Awareness Panel** – provides the user with reminders on who can see the content they have or will disclose, what is done with it, why, and how it might become identifiable. This would help developers to comply with the Transparency principle of the CPLF and granting participants the Right to be Informed. Similarly, pattern 61 – **Personal Data Table** – maintains the tracking of the processing of personal data to enable users to view the activities and preferences concerning their data and review the preferences they have made in a tabular format. Accordingly, developers would be complying with the Transparency principle of the CPLF and granting participants the Right of Individuals Access, and the Right of the Individual to Exercise their Rights. According to pattern 28 – **Trust Evaluation of Services Slides** –, it is important for the participants to trust the service that is provided by the gym and make sure that the service does not negatively affect their personal privacy requirements. This would result in complying directly with the Transparency and Accountability principles of the CPLF and granting users the Right to be Informed.

As demonstrated in Figure 7, the Gym Activity application sends the personal data to be stored in the local server, and the local server pushes the data to the IoT cloud for further analysis, which could be managed by a third party. Thus, applying privacy pattern 18 – **Outsourcing [with consent]** – is crucial before allowing the third party to process their data. This would result in complying directly with the Limiting Use and Disclosure, Consent, and Lawfulness of Processing principles. It also helps developers to adhere indirectly with the Accountability principle, and the Purpose Limitation principle, where the purpose should be specified to limit the use and disclosure of the data collected for that purpose. Like pattern 32 – **Sign an Agreement to Solve Lack on a Use of Private Data Context** – which means that the controller must provide the user with a contractual agreement, as that will cause the controller to be more dedicated to keeping their word. In a similar fashion, pattern 40 – **Obtaining Explicit Consent** – requires the controller to obtain unambiguous consent from the user in order to collect, store, and analyse their personal data, either by using Contractual Consent or by signifying their consent. For example, a check box that allows participants to provide their consent through checking the box. Applying patterns 32 and 40 would result in complying directly with the Consent, and Lawfulness of Processing principle, and indirectly with the Accountability principle. This is similar to pattern 58 – **Lawful Consent** – which covers in detail the legal and social obligations surrounding a data subject's consent to processing of their data in specific circumstances. This consent of the participants should be purposed-separated, so the controller should obtain consent for the collection of data when a participant starts a workout and should obtain consent for storing data in the IoT cloud, and so on. Therefore, developers will be adhering directly to the Purpose Limitation, Consent, and Lawfulness of Processing principles.

The controller of the Gym Activity application has to maintain privacy policies as they are an essential part of the processing required for its activities. Furthermore, they do not just rely on the users, which is an important part of the processing, but also implement the laws that mandate these policies. Privacy patterns 10, 11, 15, 20, 21, 30, 36, 37, 39, 45 and 59 all concentrate on solving the privacy issues addressed in privacy policies. This is because privacy policies typically tend to be complicated and very long. In addition, the privacy patterns involved address balancing the accessibility set out in these policies alongside adhering to the legal comprehensiveness required. Moreover, these patterns attempt to clearly set out privacy policies so that users remain properly informed of the way their personal data is being processed. For example, pattern 20 – **Dynamic Privacy Policy** – requires a controller to

present the user with extra policy information that is relevant to them as and when needed, according to the context. This would result in complying with the Transparency principle of the law and granting users the Right to be Informed.

In a case where participants share their photograph with other participants, it is safer to remove all of the metadata (ex., location of the photo) not directly visible during upload time or while the service is being used. This will protect personal information from leaks, and prevent the controllers from surprising users, which could alienate them, if the information does not have legal protection. This applies pattern 25 – **Strip Invisible Metadata** – which helps developers to directly comply with the Data minimisation and the Limiting Use and Disclosure principles of the CPLF. It also adheres to the Purpose Limitation and the Accountability principles indirectly. As the participants can share their workout and pictures with other participants, the controller has to use privacy warnings that are contextual to present relevant information and provide suggestions about pending disclosures. This applies privacy patterns 43 – **Impactful Information and Feedback** – which would help developers to comply with part of the CPLF by granting the participants the Right to be Informed.

As the Gym Activity application requires the participants to register their names, the application should allow the participants to identify themselves by using a pseudonym. Pattern 26 – **Pseudonymous Identity** – ensures a pseudonymous identity not to be linked with a real identity. This would result in complying directly with the Anonymity and Pseudonymity principle of the CPLF and complying indirectly with the Security and the Accountability principles. With regard to users' preferences, pattern 53 – **Negotiation of Privacy Policy** – requires the controller to specify their participants' privacy preferences; also, if the user's preference is unclear or unknown, it must assume the highest privacy-preserving setting levels. The controller in this scenario, could enable data collection once a participant starts a workout by default, unless the participant disables the data collection. However, none of the principles and rights of the CPLF are suited to this privacy pattern. Applying pattern 35 – **Enable/Disable Function** – allows participants to enable and disable any service provided by the application, such as disabling the heart rate monitor sensor or disabling the service that enables them to share their workouts with other participants. When developers apply this pattern, they would be directly complying with the Consent and the Transparency principles, and the Right to be Informed. They would also be adhering to the Accountability and the Lawfulness of Processing principles indirectly. Privacy pattern 46 – **Selective Access control** – allows a participant to specify the participants who can access their content based on a specified rule, such as a rule that is based on participants, or a rule based on context-aiding attributes like age. This would result in complying directly with the Security principle of the CPLF. Allowing participants the option to clarify the privacy level for the content shared with the controller or other users means that they can decide on the level of access given to other participants. This applies pattern 12 – **Discouraging Blanket Strategies**; however, none of the principles and rights of the CPLF is achieved by this pattern. Applying pattern 54 – **Reasonable Level of Control** – enables participants to access information, a service, or other participants, in a selective manner, and make information available to predetermined groups or groups denied by the user. Like pattern 56 – **Buddy List** – which facilitates users finding and assigning others to a directory that is user maintained and contains social circles and contexts for interacting with. Therefore, applying pattern 50 – **Preventing Mistakes or Reducing their Impact** – prevents unintended disclosure of personal information to other participants. It requires the controller to put contextual measures in place in order to predict whether content needs to be processed, or if consent should be re-established, to stop unintentional disclosure and mistakes. This would result in directly adhering to the Limiting Use and Disclosure principle of the CPLF and would grant participants the Right to be Informed.

Pattern 41 – **Privacy Mirrors** – requires the controller to provide the user with access to the personal data processed, including the history, flow, state and nature of that data. This, in turn, would help developers to grant participants the Right to be Informed and the Right to Individuals Access. Pattern 48 – **Privacy Dashboard** – is wider as it does not only grant access to the user, but it also allows them to easily control their data and the various permissions, such as amending, erasing or modifying the purposes that they can be used for, or the parties it is allowed to share them with, if applicable. Accordingly, developers would be complying with most of the rights of the CPLF: the Right of Individuals

to Exercises their Rights, the Right to be Informed, the Right to Individuals Access, the Right to Rectification, the Right to Erase, the Right to Restriction of Processing, the Right to Object, the Right to Object to Marketing, the Right to Object to Automated Decision-making, and the Right to Withdraw consent. It would also help them to adhere indirectly to the Accountability principles.

(2) **Applying Privacy Patterns to the Local Server and the IoT Cloud:**

As each workout information is stored in the local server once a participant completes the workout, it is essential to ensure that personal information is kept confidential by applying privacy pattern 6 – **Encryption with a User-managed Key** to the local server and to the IoT cloud. Developers could also apply pattern 24 – **Onion Routing** – to protect personal data while it is routed between different nodes. Furthermore, while the completed workout for each month is sent to the IoT cloud for analysis purposes, it is good practice to increase the security of the personal information before sending it to the cloud as this could be prevent any exploitation of personal data. Accordingly, applying these privacy patterns would help developers to directly comply with the security principle of the CPLF and the Accountability principle indirectly. Furthermore, applying privacy pattern 8 – **Use of Dummies** – would help developers to secure personal information by adding fake workouts to the real workout in an approach that prevents the adversary from distinguishing real from fake information. This, in turn, would help developers to adhere to the Security and Anonymity and Pseudonymity principles of the CPLF.

According to pattern 28 – **Trust Evaluation of Services Slides** –, it is important for participants to trust the service that is provided by the gym and make sure that a service will not undermine personal privacy requirements. This pattern is not only limited to the local server and IoT cloud, but is also applicable to the smart watch. This would result in complying directly with the Transparency and the Accountability principles of the CPLF, as well as granting participants the Right to be Informed. Regarding the services that could be managed by a third party such as the IoT cloud in this scenario, it is important to apply privacy pattern 29 – **Aggregation Gateway** – which implements homomorphic encryption by using a secret answer that is shared with the third party aiming to improve the system. The third-party will not know what the content is because it is encrypted, and so it operates on the data in an encrypted format. This encryption prevents any revealing of the user's health and fitness information. Accordingly, the service provider would comply with the security principle of the law directly. Introducing privacy pattern 63 – **Added-noise Measurement Obfuscation** – ensures that any information that may reveal sensitive user information cannot be accessed. By storing fake workouts, for example, its difficult to infer any other personal information from the aggregation of the user's information. This would help developers to comply with the principle of Limiting Use and Disclosure of the CPLF directly. To prevent any consequences resulting from a data breach, it is crucial to apply privacy pattern 22 – **Data Breach Notification Pattern** – to the local server and to the IoT cloud in order to detect and react to a data breach quickly and to prevent any malicious activity using personal information. Accordingly, developers would be complying with the Security and the Accountability principles of the CPLF.

Since the data could be accessed or handled by a third party (the IoT cloud in this scenario) where the controller shares the data in ways that may not be approved by the participant, applying privacy pattern 50 – **Obligation Management** – ensures that the third party knows about and complies with the necessary user or organisational policies. Accordingly, developers would be adhering directly with the principle of the Data Minimisation, Storage Limitation, and Accountability. It also helps developers to grant participants the Right to be informed. It is similar to the privacy pattern 60 – **Sticky Policy**.

## 8 RESEARCH CHALLENGES AND OPPORTUNITIES

In this section, the objective is to identify some of the major challenges that should be addressed, and potential research directions in order to support software developers building privacy-aware IoT applications. These challenges have not been addressed yet in academia and they are as follows: prioritising the privacy patterns, creating new privacy patterns, enriching developers' tools to support privacy, and building privacy by design tools.



### 8.1 Prioritizing the Privacy Patterns

As shown in Section 6.3 in Table 8, various privacy patterns have been mapped to different principles and rights of the CPLF in order to facilitate developers complying with data protection laws. Privacy patterns provide an important reference point for developers [47, 48]. However, they are often introduced during a fairly late stage of the design after key choices and decisions have been made; even so, they assist with documenting common practices and standardising terminology. From a practical perspective, however, there are still problems around developers having the competence needed to choose patterns and implement the ones most relevant to the artifacts being designed. Accordingly, making the right decision and trade-offs regarding the choice of a privacy pattern, from among all the available patterns without compromising the core functionality of a system, would stand as a barrier to software developers.

Figure 8 demonstrates the prioritisation of the privacy patterns based on the number of key principles and/or individual’s rights of the CPLF achieved. We cannot claim that a particular pattern is more important than another just because it achieves many numbers of principles and/or rights. To illustrate, privacy pattern 17 – **Privacy Dashboard** – achieves eleven of the principles and rights (1 principle, 10 rights) of the CPLF. However, it mainly focuses on the individual’s access and it does not consider other important principles, such as Data Minimisation, despite all the data protection laws in this study asserting the importance of achieving this principle. Therefore, prioritising the privacy patterns based on the number of achieved principles and/or rights of the CPLF is not useful.

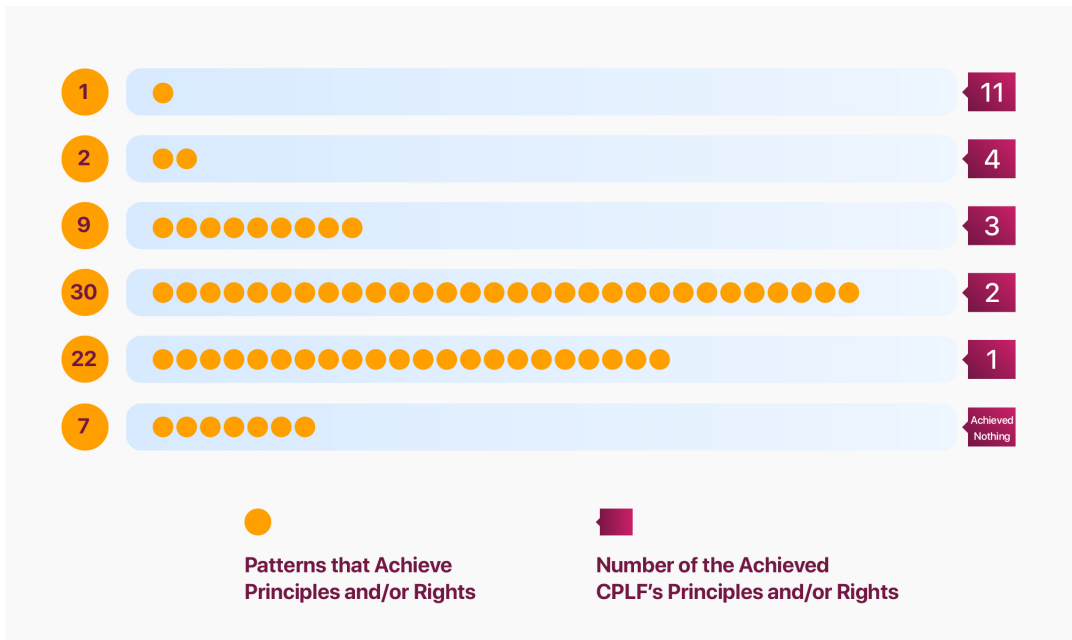


Fig. 8. Prioritisation of the privacy patterns

Figures 9 and 10 show another way of prioritisation of privacy patterns. It ranks the CPLF’s principles and rights based on the agreement of the issuers of the data protection laws of the five selected countries on a specific principle/right according to the criteria mentioned below. That means that if a data protection law agrees with the concept of a specific principle/right, this principle/right will attain a score of two for that issuer. And, when the issuer’s view is not explicitly stated but agrees with the concept of this principle/right, this principle/right will get a score of one for that issuer, or otherwise nothing. Nonetheless, there is a need for scientific evidence for the prioritisation process.

---

✓	If the issuer’s view agrees with the concept of this key principle/right
☑	If the issuer’s view is not explicitly stated but agrees with the concept of this key principle/right being inferred from such a provision
N/M	If a regulation contains an explicitly stated provision for a different context from this key principle/right
N/A	If no provision can be assigned as the issuer’s view and there is no contradiction with this principle/ right

---



Fig. 9. Prioritisation of the privacy patterns based on the ranking of the CPLF’s principles

Even though Jason Hong’s team of PrivacyGrade.org has graded one million Android Apps based on their usage of sensitive information [20], no previous study has investigated the prioritisation of privacy patterns to help developers make the right decision and trade-off regarding the choice of privacy-preserving ideas. Therefore, developers can balance between the privacy-preserving techniques and the core functionality of the system.

### 8.2 Creating New Privacy Patterns

As seen in Section 6.3 in Table 8, synthesising various Privacy by Design (PbD) schemes into a single knowledge base, captures the relationship between the principles, strategies, and guidelines of the PbD schemes after they have been largely disconnected from each other. This knowledge base supports software developers in discovering the privacy protection mechanisms required to solve the problem at hand swiftly and efficiently. It also shows how some of the schemes were extended based on other schemes, and how some of the schemes’ phrases are connecting with each other. However, correlating the principles, strategies, and guidelines of the PbD schemes with the principles and rights of the CPLF reveals that there is a need to improve the existing



Fig. 10. Prioritisation of the privacy patterns based on the ranking of the CPLF's rights

principles, strategies, and guidelines or to propose new PbD schemes in order to mitigate the gap with regard to the rules of the various data protection laws, as shown in Tables 3, 4, 5, 6, and 7.

Nevertheless, as stated previously, privacy patterns are more solid and more appropriate for explaining data usage in a specific context, and are more effective than the principles, guidelines or strategies of the PbD scheme. As shown previously in Table 8, mapping between the privacy patterns and the principles and rights of the CPLF indicates that various principles and rights of the CPLF have not been achieved by any of the existing privacy patterns. These are the principles: **Source**, **Cross-border Disclosure of Personal Information**, **Dealing with Unsolicited Data**, and **Adoption, Use, and Disclosure of an Identifier**; and these are the rights: **Right to Data Portability**, **Right to Complain**, and the **Right of Individuals not to be Discriminated**. Furthermore, the problem is not only limited to the applicability of a particular privacy pattern to achieve a certain law, but the applicability of implementing the same pattern in different ecosystems as there are few operating-system-specific details. Let us take – **Location Granularity** – as an example of a pattern. Implementing this pattern in Arduino is different from implementing the same pattern in Raspberry Pi, which has a different operating system. Privacy patterns, however, can still be identified as low-level designs that help software developers to build a privacy-aware system. Therefore, harnessing the effort not only to create new general privacy patterns that cover all the rules of the data protection laws, but also to create IoT specific privacy patterns while taking into consideration various ecosystems, would help IoT developers to comply with data protection laws and to build privacy-aware IoT applications.

### 8.3 Enriching Developers' Tools to Support Privacy

In order to build a privacy-aware IoT application that complies with the rules of data protection law, software developers need to deal effectively with the legal aspects of it, understand its provisions, and translate these legal requirements into technical requirements that are applicable to the technical domain. However, as stated previously, studies have shown that developers from a range of backgrounds often lack the skills necessary to ensure effective privacy management [6, 59], and the difficulties that exist in regard to compliance with regulations are predicted to increase in the future [5]. While some guidelines are available, most concentrate on the legal aspects, rather than technical requirements, which results in them being unsuitable for the tools used

to build applications, and this disconnects them from the practical environment that developers are working in. Thus, developers face the problem of relating the guidance provided to actual technical considerations, such as ensuring a specific design, or making sure its implementation properly meets privacy requirements.

As shown earlier in this paper, in order to help developers across different regions exceed these obstacles, different data protection laws of various countries have been analysed. This analytical method shows how dealing with legal aspects is a very complicated process, as there are vague provisions that need to be understood and various key principles and individual rights that should be taken into consideration. Investigating the previous efforts on guiding software designers and developers to protect personal information, several researchers have proposed various principles, guidelines, strategies and patterns of the PbD schemes. Nevertheless, after correlating these privacy schemes with the key principles and rights, it has been demonstrated that not only are many of these principles, strategies, and guidelines disconnected from the technical domain, but they are not adhering to the rules of the CPLF. A further issue is demonstrated when applying privacy patterns to different use cases, as patterns are more appropriate than principles, strategies, and guidelines. This reveals how it is difficult for software developers to choose the right position of a pattern where the IoT scenario is complicated, and where the data moves between many nodes that have different computational capabilities. It is, moreover, difficult for developers to make the right decision and trade-off regarding the choice of a privacy pattern from among all the available patterns without compromising the core functionality of the system. The problem is not only limited to these challenges but, moreover, there is a lack of practical guidance that considers the technical domain for developers to build a privacy-aware IoT application [23].

Enriching existing developers' tools to support privacy-preserving techniques will ensure that developers are more aware of the use of personal data and how it can potentially be exploited, throughout the process of application building. In addition, this shift in emphasis will lead developers to consider the implications of their applications, and the possibility of using alternatives that pose less risk when personal data is involved. Precisely, through introducing notions of privacy into the development environment, the environment itself could provide guidance that specifically addresses the artifacts being built, and this may enable software developers to better adhere to the provisions required by law. This will not only place the burden on software developers, but will also save developers time and effort.

#### 8.4 Building Privacy By Design Tools

According to Roeser (2012), "Engineers can influence the possible risks and benefits more directly than anybody else" [51]. Even so, software engineers typically face a number of issues concerning privacy management. For example, they may pass the responsibility over to experts; however, this is based on the assumption that software engineers have access to such experts, even though this is unlikely for small businesses or individual designers. In addition, privacy experts need to have the technical competence to understand the impact of development decisions on privacy [24]. While guidelines exist, they are usually geared towards a legal rather than technical domain, and are generally disconnected from the tools and environments used by developers to design their applications. Moreover, privacy guidelines are usually drawn on during the latter stages of the design phase, even though their application would be easier and more effective if they were applied earlier. In addition, software engineers face the challenge of relating guidance to technical aspects, but this guidance may not align with some design choices or implementation details.

In contrast, as shown previously in Section 3, analysing the data protection laws of various countries is a very complicated process, as there may be vague provisions that are difficult to understand, and key principles and individual rights that must be considered. Research has shown that previous efforts to guide software designers to ensure the protection of personal information, has led to a number of principles, guidelines, strategies and patterns of Privacy by Design (PbD) schemes being proposed. The mapping between these privacy schemes and the key principles and rights is time consuming where software designers have to do so manually. Even so, once these privacy schemes have been correlated with the key principles and rights, it has been shown that many principles, strategies, and guidelines are disconnected from the technical domain; furthermore, they often do not adhere to the rules of the CPLF. Another issue involves applying privacy patterns to different use cases, where patterns are more concrete than principles, strategies or guidelines. Therefore, it is difficult for software developers to choose the position of a pattern if the IoT scenario is complicated, and if the data moves between several nodes with different computational capabilities and

constraints on resources. It is, moreover, difficult for developers to make the right decision and trade-off regarding the choice of a privacy pattern from among all the available patterns without compromising the core functionality of a system. The problem is wider than these challenges, yet there is a lack of practical guidance for designers in the technical domain to support the design phase of building IoT applications.

Placing a greater focus on the development of privacy tools as a central aspect of the design process, and not simply as an additional factor, will ensure that software engineers pay more consideration to personal data, and its potential to be exploited throughout the process of application design. In addition, this shift in focus should encourage software engineers to consider the implications of specific IoT application designs, including whether to use alternatives that pose less risk to personal data. Furthermore, privacy by design tools will not only remove the burden from software designers, but will also save time and effort, which will make this process of designing a privacy-aware IoT application faster, more reliable and consistent.

### 8.5 Using Gamification Techniques

In order to engage and motivate software designers and developers building a privacy-aware IoT application, the technique of play gamification has recently emerged. This is the use of game mechanics and related elements within various contexts [49]. Using gamification [2, 56] in the design and development stage is a useful and innovative way of increasing productivity and motivation, and companies that have used this approach have seen increased productivity and greater involvement [16, 56] of software designers and developers in applying privacy patterns. This is because gamification enables people to learn new material, as well as gaining practical knowledge through engaging in certain activities. Moreover, a large number of studies have shown the positive impact of gamification on training outcomes [43].

The components typically used in gamification are points, as these are convenient for realisation and players can understand them. In this system, for each action performed, the user gains a point [3]. Therefore, in order to guide software designers and developers, it is essential to have a marking scheme to base the points on when using gamification techniques. Prioritisation of the privacy patterns is one of the approaches that we could base the points on. As shown in the previous section, the privacy patterns were prioritised based on the ranking of each achieved principle/right of all the CPLF. So, once a software designer or a developer chooses a specific pattern, he/she will gain a score based on the prioritisation's ranking of that pattern, as seen in Figure 9 and 10. Nevertheless, as stated previously, there is a need for an in-depth understanding and scientific evidence of how prioritisation should be carried out to ensure privacy.

## 9 CONCLUSION

Developers of IoT applications, like any other developers, face difficulties when adhering to data protection laws and the associated Privacy by Design (PbD) techniques. However, developers from a range of backgrounds have a tendency not to be fully skilled in privacy management, and problems around adhering to regulations are predicted to increase even more in the future. It is, therefore, essential for developers to make an effort to meet data protection requirements and to comply with the law. In this investigation, the aim was to assist developers in understanding legal requirements, to map these legal requirements to various PbD schemes in order to build better privacy-aware IoT applications, and to comply with data protection law. Various data protection laws have been analysed, which are the General Data Protection Regulations (GDPR), the Personal Information Protection and Electronic Documents Act (PIPEDA), California Consumer Privacy Act (CCPA), Australian Privacy Principles (APPs), and New Zealand's Privacy Act 1993. Then, existing PbD techniques were reviewed and correlated to the principles, strategies, and guidelines, along with the key principles and individuals' rights in the CPLF. In addition, the privacy patterns were mapped – as they are more concrete – with the privacy laws and it was demonstrated how to apply the privacy patterns to the right position of a given IoT architecture. Applying the privacy patterns to IoT architectures helps developers to highlight the privacy challenges, which, in turn, would help them comply with the law as they have been correlated. This study concludes that the major challenges that have to be resolved to achieve effective privacy protection in IoT applications are: prioritising the privacy patterns, creating new privacy patterns for IoT and operating system specific domains, enriching developers' tools to support privacy, and building privacy by design tools.

## REFERENCES

- [1] Yasemin Acar, Sascha Fahl, and Michelle L. Mazurek. 2016. You are Not Your Developer, Either: A Research Agenda for Usable Security and Privacy Research Beyond End Users. *Proceedings - 2016 IEEE Cybersecurity Development, SecDev 2016* (2016), 3–8. <https://doi.org/10.1109/SecDev.2016.013>
- [2] Satoshi Arai, Kazunori Sakamoto, Hironori Washizaki, and Yoshiaki Fukazawa. 2014. A gamified tool for motivating developers to remove warnings of bug pattern tools. *Proceedings - 2014 6th International Workshop on Empirical Software Engineering in Practice, IWESEP 2014* (2014), 37–42. <https://doi.org/10.1109/IWESEP.2014.17>
- [3] Darius Ašeriškis and Robertas Damaševičius. 2014. Gamification patterns for gamification applications. *Procedia Computer Science* 39, C (2014), 83–90. <https://doi.org/10.1016/j.procs.2014.11.013>
- [4] Vanessa Ayala-Rivera and Liliana Pasquale. 2018. The grace period has ended: An approach to operationalize GDPR requirements. *Proceedings - 2018 IEEE 26th International Requirements Engineering Conference, RE 2018* (2018), 136–146. <https://doi.org/10.1109/RE.2018.00023>
- [5] Rebecca Balebako and Lorrie Cranor. 2014. Improving app privacy: Nudging app developers to protect user privacy. *IEEE Security and Privacy* 12, 4 (2014), 55–58. <https://doi.org/10.1109/MSP.2014.70>
- [6] Rebecca Balebako, Abigail Marsh, Jialiu Lin, Jason Hong, and Lorrie Faith Cranor. 2014. The Privacy and Security Behaviors of Smartphone App Developers. In *Proceedings 2014 Workshop on Usable Security* (2014). <https://doi.org/10.14722/usec.2014.23006>
- [7] Len Bass, Paul Clements, and Rick Kazman. 2003. *Software Architecture in Practice Addison-Wesley*. Vol. 3. Addison Wesley. 662 pages.
- [8] Frank Buschmann, Regine Meunier, Hans Rohnert, Peter Sommerlad, and Michael Stal. 1996. *Pattern-Oriented Software Architecture, A System of Patterns*. Vol. 1. <https://doi.org/10.1192/bjp.108.452.101>
- [9] Fred H Cate. 2006. The Failure of Fair Information Practice Principles. *Consumer Protection in the Age of the 'Information Economy'* (2006), 341–377.
- [10] Ann Cavoukian. 2010. Privacy by Design. *Identity in the Information Society* 3, 2 (2010), 1–12. <https://doi.org/10.1007/s12394-010-0062-y>
- [11] Ann Cavoukian and Jeff Jonas. 2012. Privacy by Design in the Age of Big Data. *Information and Privacy Commissioner* June (2012), 1–17. <https://doi.org/10.1126/science.aaa5945>
- [12] B. Costa, P. F. Pires, F. C. Delicato, W. Li, and A. Y. Zomaya. 2016. Design and Analysis of IoT Applications: A Model-Driven Approach. In *2016 IEEE 14th Intl Conf on Dependable, Autonomic and Secure Computing, 14th Intl Conf on Pervasive Intelligence and Computing, 2nd Intl Conf on Big Data Intelligence and Computing and Cyber Science and Technology Congress (DASC/PiCom/DataCom/CyberSciTech)*. 392–399.
- [13] Daniel E. O'leary. 1995. Some Privacy Issues in Knowledge Discovery: The OECD Personal Privacy Guidelines. *IEEE Expert-Intelligent Systems and their Applications* 10, 2 (1995), 48–59. <https://doi.org/10.1109/64.395352>
- [14] Gina Fisk, Calvin Ardi, Neale Pickett, John Heidemann, Mike Fisk, and Christos Papadopoulos. 2015. Privacy principles for sharing cyber security data. *Proceedings - 2015 IEEE Security and Privacy Workshops, SPW 2015* (2015), 193–197. <https://doi.org/10.1109/SPW.2015.23>
- [15] Christine Furber. 2010. Framework analysis: a method for analysing qualitative data. *African Journal of Midwifery and Women's Health* 4, 2 (2010), 97–100. <https://doi.org/10.12968/ajmw.2010.4.2.47612>
- [16] Gloria Piedad Gasca-Hurtado, María Clara Gómez-Alvarez, Mirna Muñoz, and Jezreel Mejía. 2016. Gamification proposal for defect tracking in software development process. In *Gamification proposal for defect tracking in software development process (Communications in Computer and Information Science)*. 212–224. [https://doi.org/10.1007/978-3-319-44817-6\\_17](https://doi.org/10.1007/978-3-319-44817-6_17)
- [17] Jayavardhana Gubbi, Rajkumar Buyya, Slaven Marusic, and Marimuthu Palaniswami. 2013. Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems* 29, 7 (2013), 1645–1660. <https://doi.org/10.1016/j.future.2013.01.010> arXiv:1207.0203
- [18] Irit Hadar, Tomer Hasson, Oshrat Ayalon, Eran Toch, Michael Birnhack, Sofia Sherman, and Arod Balissa. 2018. Privacy by designers: software developers' privacy mindset. *Empirical Software Engineering* 23, 1 (2018), 259–289. <https://doi.org/10.1007/s10664-017-9517-1>
- [19] Jaap-henk Hoepman. 2014. IFIP AICT 428 - Privacy Design Strategies. (2014), 446–459. [https://link.springer.com/content/pdf/10.1007/978-3-642-55415-5\\_{\\_}38.pdf](https://link.springer.com/content/pdf/10.1007/978-3-642-55415-5_{_}38.pdf)
- [20] Jason Hong. 2017. The Privacy Landscape of Pervasive Computing. *IEEE Pervasive Computing* 16, 3 (2017), 40–48. <https://doi.org/10.1109/MPRV.2017.2940957>
- [21] Marc Langheinrich. 2001. Privacy by Design — Principles of Privacy-Aware Ubiquitous Systems. In *Ubicomp 2001: Ubiquitous Computing*, Gregory D. Abowd, Barry Brumitt, and Steven Shafer (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 273–291.
- [22] California State Legislature. 2018. Bill Text - AB-375 Privacy: personal information: businesses. [https://leginfo.ca.gov/faces/billTextClient.xhtml?bill\\_id=201720180AB375](https://leginfo.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB375)

- [23] Tianshi Li and Jason I Hong. 2018. Coconut: An IDE Plugin for Developing Privacy-Friendly Apps. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 2, 4 (2018). <https://doi.org/10.1145/3287056>
- [24] Tom Lodge and Andy Crabtree. 2019. Privacy Engineering for Domestic IoT : Enabling Due Diligence. (2019).
- [25] Kai Uwe Loser and Martin Degeling. 2014. Security and Privacy as Hygiene Factors of Developer Behavior in Small and Agile Teams. *IFIP Advances in Information and Communication Technology* 431 (2014), 255–265. [https://doi.org/10.1007/978-3-662-44208-1\\_21](https://doi.org/10.1007/978-3-662-44208-1_21)
- [26] Office of the Australian Information Commissioner. 2013. Australian Privacy Principles – OAIC. <https://www.oaic.gov.au/privacy/australian-privacy-principles/>
- [27] Office of the Australian Information Commissioner. 2013. Interpretation Bulletin: Accuracy - Office of the Privacy Commissioner of Canada. [https://www.priv.gc.ca/en/privacy-topics/privacy-laws-in-canada/the-personal-information-protection-and-electronic-documents-act-pipeda/pipeda-compliance-help/pipeda-interpretation-bulletins/Accuracy\\_{\\_}04\\_{\\_}accuracy/](https://www.priv.gc.ca/en/privacy-topics/privacy-laws-in-canada/the-personal-information-protection-and-electronic-documents-act-pipeda/pipeda-compliance-help/pipeda-interpretation-bulletins/Accuracy_{_}04_{_}accuracy/)
- [28] Office of the Australian Information Commissioner. 2014. Australian Privacy Principles quick reference – OAIC. <https://www.oaic.gov.au/privacy/australian-privacy-principles/australian-privacy-principles-quick-reference/>
- [29] Office of the Australian Information Commissioner. 2014. Rights and responsibilities – OAIC. <https://www.oaic.gov.au/privacy/the-privacy-act/rights-and-responsibilities/>
- [30] Office of the Australian Information Commissioner. 2018. Australian entities and the EU General Data Protection Regulation (GDPR) – OAIC. <https://www.oaic.gov.au/privacy/guidance-and-advice/australian-entities-and-the-eu-general-data-protection-regulation/>
- [31] Office of the Australian Information Commissioner. 2019. Chapter B: Key concepts – OAIC. <https://www.oaic.gov.au/privacy/australian-privacy-principles-guidelines/chapter-b-key-concepts/>
- [32] Office of the Privacy Commissioner. 2013. AskUs | Article | When does a privacy waiver expire? | Office of the Privacy Commissioner. <https://privacy.org.nz/further-resources/knowledge-base/view/341>
- [33] Office of the Privacy Commissioner of Canada. [n.d.]. PIPEDA legislation and related regulations - Office of the Privacy Commissioner of Canada. [https://www.priv.gc.ca/en/privacy-topics/privacy-laws-in-canada/the-personal-information-protection-and-electronic-documents-act-pipeda/r\\_{\\_}o\\_{\\_}p/](https://www.priv.gc.ca/en/privacy-topics/privacy-laws-in-canada/the-personal-information-protection-and-electronic-documents-act-pipeda/r_{_}o_{_}p/)
- [34] Office of the Privacy Commissioner of Canada. 2013. AskUs | Article | Do we have to report data breaches? | Office of the Privacy Commissioner. <https://www.privacy.org.nz/further-resources/knowledge-base/view/331>
- [35] Office of the Privacy Commissioner of Canada. 2013. Office of the Privacy Commissioner | Introduction. <https://www.privacy.org.nz/the-privacy-act-and-codes/privacy-act-and-codes-introduction/>
- [36] Office of the Privacy Commissioner of Canada. 2013. Office of the Privacy Commissioner | Your Right To Know - an OPC advice sheet. <https://www.privacy.org.nz/news-and-publications/guidance-resources/your-right-to-know-an-opc-advice-sheet/>
- [37] Office of the Privacy Commissioner of Canada. 2016. Businesses and your personal information - Office of the Privacy Commissioner of Canada. <https://www.priv.gc.ca/en/privacy-topics/information-and-advice-for-individuals/your-privacy-rights/businesses-and-your-personal-information/>
- [38] Office of the Privacy Commissioner of Canada. 2016. How the OPC protects and promotes privacy - Office of the Privacy Commissioner of Canada. <https://www.priv.gc.ca/en/about-the-opc/what-we-do/mm/>
- [39] Office of the Privacy Commissioner of Canada. 2016. Office of the Privacy Commissioner | Commissioner of the privacy principles. <https://www.privacy.org.nz/news-and-publications/guidance-resources/a-quick-tour-of-the-privacy-principles/>
- [40] Office of the Privacy Commissioner of Canada. 2018. Summary of privacy laws in Canada - Office of the Privacy Commissioner of Canada. [https://www.priv.gc.ca/en/privacy-topics/privacy-laws-in-canada/02\\_05\\_d\\_15/](https://www.priv.gc.ca/en/privacy-topics/privacy-laws-in-canada/02_05_d_15/)
- [41] Office of the Privacy Commissioner of Canada. 2018. What you need to know about mandatory reporting of breaches of security safeguards - Office of the Privacy Commissioner of Canada. [https://www.priv.gc.ca/en/privacy-topics/business-privacy/safeguards-and-breaches/privacy-breaches/respond-to-a-privacy-breach-at-your-business/gd\\_pb\\_201810/](https://www.priv.gc.ca/en/privacy-topics/business-privacy/safeguards-and-breaches/privacy-breaches/respond-to-a-privacy-breach-at-your-business/gd_pb_201810/)
- [42] Office of the Privacy Commissioner of Canada. 2019. PIPEDA fair information principles - Office of the Privacy Commissioner of Canada. [https://www.priv.gc.ca/en/privacy-topics/privacy-laws-in-canada/the-personal-information-protection-and-electronic-documents-act-pipeda/p\\_principle/](https://www.priv.gc.ca/en/privacy-topics/privacy-laws-in-canada/the-personal-information-protection-and-electronic-documents-act-pipeda/p_principle/)
- [43] Erick B. Passos, Danilo B. Medeiros, Pedro A.S. Neto, and Esteban W.G. Clua. 2011. Turning real-world software development into a game. *Brazilian Symposium on Games and Digital Entertainment, SBGAMES* (2011), 260–269. <https://doi.org/10.1109/SBGAMES.2011.32>
- [44] Charith Perera, Mahmoud Barhamgi, Arosha K. Bandara, Muhammad Ajmal, Blaine Price, and Bashar Nuseibeh. 2019. Designing Privacy-aware Internet of Things Applications. (2019). arXiv:1703.03892 <http://arxiv.org/abs/1703.03892>
- [45] Charith Perera, Chi Harold Liu, and Srimal Jayawardena. 2015. The Emerging Internet of Things Marketplace from an Industrial Perspective: A Survey. *IEEE Transactions on Emerging Topics in Computing* 3, 4 (2015), 585–598.

<https://doi.org/10.1109/TETC.2015.2390034> arXiv:1502.00134

- [46] Charith Perera, Arkady Zaslavsky, Peter Christen, and Dimitrios Georgakopoulos. 2014. Context aware computing for the internet of things: A survey. *IEEE Communications Surveys and Tutorials* 16, 1 (2014), 414–454. <https://doi.org/10.1109/SURV.2013.042313.00197> arXiv:1305.0982
- [47] privacypatterns.org. [n.d.]. Patterns - Privacy Patterns. <https://privacypatterns.org/patterns/>
- [48] privacypatterns.org. [n.d.]. privacypatterns.eu - collecting patterns for better privacy. <https://privacypatterns.eu/#?limit=6&offset=0>
- [49] Claudia Ribeiro, Carla Farinha, João Pereira, and Miguel Mira da Silva. 2014. Gamifying requirement elicitation: Practical implications and outcomes in improving stakeholders collaboration. *Entertainment Computing* 5, 4 (2014), 335–345. <https://doi.org/10.1016/j.entcom.2014.04.002>
- [50] Rob van der Meulen and Gartner. 2017. Gartner Says 6.4 Billion Connected "Things" Will Be in Use in 2016, Up 30 Percent From 2015. <https://www.gartner.com/en/newsroom/press-releases/2017-02-07-gartner-says-8-billion-connected-things-will-be-in-use-in-2017-up-31-percent-from-2016>
- [51] Sabine Roeser. 2012. Emotional Engineers: Toward Morally Responsible Design. *Science and Engineering Ethics* 18, 1 (2012), 103–115. <https://doi.org/10.1007/s11948-010-9236-0>
- [52] Rodrigo Roman, Jianying Zhou, and Javier Lopez. 2013. On the features and challenges of security and privacy in distributed internet of things. *Computer Networks* 57, 10 (2013), 2266–2279. <https://doi.org/10.1016/j.comnet.2012.12.018>
- [53] Martin Rost and Kirsten Bock. 2011. Privacy by Design and the New Protection Goals. *DuD, January* November 2009 (2011), 1–9. <https://www.european-privacy-seal.eu/AppFile/GetFile/ca6cdc46-d4dd-477d-9172-48ed5f54a99c>
- [54] Laurens Sion, Kim Wuyts, Koen Yskout, Dimitri Van Landuyt, and Wouter Joosen. 2018. Interaction-Based Privacy Threat Elicitation. *Proceedings - 3rd IEEE European Symposium on Security and Privacy Workshops, EURO S and PW 2018* (2018), 79–86. <https://doi.org/10.1109/EuroSPW.2018.00017>
- [55] Aashish Srivastava and S Bruce Thomson. 2009. Framework analysis: a qualitative methodology for applied policy research. (2009).
- [56] Jakub Swacha. 2016. Gamification in Enterprise Information Systems: What, why and how. *Proceedings of the 2016 Federated Conference on Computer Science and Information Systems, FedCSIS 2016* 8 (2016), 1229–1233. <https://doi.org/10.15439/2016F460>
- [57] the European Commission. 2012. INTERNATIONAL STANDARD ISO / IEC: Information technology – Security techniques – Guidelines for cybersecurity. 2012 (2012), 58.
- [58] the European Commission. 2016. L\_2016119EN.01000101.xml. <https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32016R0679{&}from=EN{#}d1e2793-1-1>
- [59] Yung Shin Van Der Sype and Walid Maalej. 2014. On lawful disclosure of personal user data: What should app developers do? *2014 IEEE 7th International Workshop on Requirements Engineering and Law, RELAW 2014 - Proceedings* (2014), 25–34. <https://doi.org/10.1109/RELAW.2014.6893479>
- [60] David Wright and Charles Raab. 2014. Privacy principles, risks and harms. *International Review of Law, Computers and Technology* 28, 3 (2014), 277–298. <https://doi.org/10.1080/13600869.2014.913874>
- [61] Wei Xiong, Hanping Hu, Naixue Xiong, Laurence T. Yang, Wen Chih Peng, Xiaofei Wang, and Yanzhen Qu. 2014. Anomaly secure detection methods by analyzing dynamic characteristics of the network traffic in cloud communications. *Information Sciences* 258, 60773192 (2014), 403–415. <https://doi.org/10.1016/j.ins.2013.04.009>
- [62] zebra.com. 2012. *Implementation of the "Carfinder" project*. Technical Report. [www.zebra.com](http://www.zebra.com)
- [63] Qingchen Zhang, Laurence T. Yang, Zhikui Chen, Peng Li, and M. Jamal Deen. 2018. Privacy-preserving double-projection deep computation model with crowdsourcing on cloud for big data feature learning. *IEEE Internet of Things Journal* 5, 4 (2018), 2896–2903. <https://doi.org/10.1109/JIOT.2017.2732735>
- [64] Shichao Zhang, Chengqi Zhang, and Qiang Yang. 2003. *Data preparation for data mining*. Vol. 17. 375–381 pages. <https://doi.org/10.1080/713827180>



# Appendices

## Appendix A KEY DEFINITIONS

This section articulates various definitions of different terms that are used in the regulations of the data protection laws of GDPR, PIPEDA, CCPA, Australia's Privacy Act 1988, and New Zealand's Privacy Act 1993.

### A.1 Personal Data

- **GDPR:** 'Personal Data' means 'any information relating to an identified or identifiable natural person ('data subject'); an identifiable natural person is one who can be identified, directly or indirectly, in particular by reference to an identifier such as a name, an identification number, location data, an online identifier or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person';
- **PIPEDA:** 'Personal Data' is defined under PIPEDA as 'Personal Information' that includes 'any factual or subjective information, recorded or not, about an identifiable individual. This includes information in any form, such as: age, name, ID numbers, income, ethnic origin, or blood type; opinions, evaluations, comments, social status, or disciplinary actions; and employee files, credit records, loan records, medical records, existence of a dispute between a consumer and a merchant, intentions (for example, to acquire goods or services, or change jobs)';
- **CCPA:** 'Personal Data' is defined under CCPA as 'Personal information' that means 'information that identifies, relates to, describes, is capable of being associated with, or could reasonably be linked, directly or indirectly, with a particular consumer or household'.
- **APPs:** "Personal Data" is defined under the APPS as 'Personal Information' which means 'any information or an opinion about an identified individual, or an individual who is reasonably identifiable: • whether the information or opinion is true or not; and • whether the information or opinion is recorded in a material form or not'.
- **New Zealand Privacy Act 1993:** 'Personal Data' is defined under the Privacy Act as 'Personal Information' which means 'information about an identifiable individual'.

### A.2 Data Subject

- **GDPR:** 'Data Subject' means 'an identifiable natural person who can be identified directly or indirectly'.
- **PIPEDA:** 'Data Subject' is defined under PIPEDA as 'Individuals'.
- **CCPA:** 'Data Subject' is defined under CCPA as "Consumer" which means 'a natural person who is a California resident, as defined in Section 17014 of Title 18 of the California Code of Regulations, as that section read on September 1, 2017, however identified, including by any unique identifier'.
- **APPs:** 'Data Subject' is defined under APPS as 'Individuals', which means 'a natural person'.
- **New Zealand Privacy Act 1993:** 'Data Subject' is defined under the Privacy Act 1993 as 'Individuals', which means 'a natural person'.

### A.3 Processing

- **GDPR:** 'processing' means 'any operation or set of operations which is performed on personal data or on sets of personal data, whether or not by automated means, such as collection, recording, organisation, structuring, storage, adaptation or alteration, retrieval, consultation, use, disclosure by transmission, dissemination or otherwise making available, alignment or combination, restriction, erasure or destruction';
- **PIPEDA:** 'Processing' under PIPEDA would include the use, collection, disclosure, alteration, storage or destruction of personal information.
- **CCPA:** 'Processing' is defined under CCPA 'as any operation or set of operations that are performed on personal data or on sets of personal data, whether or not by automated means. These operations would include collection and selling that are defined as:

- 'Collects,' 'collected,' or 'collection' means buying, renting, gathering, obtaining, receiving, or accessing any personal information pertaining to a consumer by any means. This includes receiving information from the consumer, either actively or passively, or by observing the consumer's behavior.
- 'Sell, 'selling,' 'sale,' or 'sold,' means selling, renting, releasing, disclosing, disseminating, making available, transferring, or otherwise communicating orally, in writing, or by electronic or other means, a consumer's personal information by the business to another business or a third party for monetary or other valuable consideration'.
- **APPs:** 'Processing' under APPS would include 'collection', 'deal', 'use', and 'disclose'.
  - 'Collection' is 'applied broadly, and includes gathering, acquiring or obtaining personal information from any source and by any means'.
  - 'Use' is not defined in the Privacy Act. 'An APP entity 'uses' information where it handles or undertakes an activity with the information, within the entity's effective control'.
  - 'Disclose' is not defined in the Privacy Act. 'An APP entity 'discloses' personal information where it makes it accessible to others outside the entity and releases the subsequent handling of the information from its effective control'.
- **New Zealand Privacy Act 1993:** 'Processing' under The Privacy Act 1993 would include 'collect', 'use', and 'disclose'.

#### A.4 Controller

- **GDPR:** 'Controller' means 'the natural or legal person, public authority, agency or other body which, alone or jointly with others, determines the purposes and means of the processing of personal data; where the purposes and means of such processing are determined by Union or Member State law, the controller or the specific criteria for its nomination may be provided for by Union or Member State law';
- **PIPEDA:** 'Controller' is referred under PIPEDA to 'organizations' which means 'private sector organizations that are not federally regulated. It does not apply to organizations that do not engage in commercial, for-profit activities'.
- **CCPA:** 'Controller' is referred under CCPA to 'business', which means 'a sole proprietorship, partnership, limited liability company, corporation, association, or other legal entity that is organized or operated for the profit or financial benefit of its shareholders or other owners, that does business in the State of California , and that satisfies one or more of the following thresholds:
  - (1) Has annual gross revenues in excess of twenty-five million dollars (\$25,000,000), as adjusted pursuant to paragraph (5) of subdivision (a) of Section 1798.185.
  - (2) Alone or in combination, annually buys, receives for the business' commercial purposes, sells, or shares for commercial purposes, alone or in combination, the personal information of 50,000 or more consumers, households, or devices.
  - (3) Derives 50 percent or more of its annual revenues from selling consumers' personal information'.
- **APPs:** 'Controller' is referred under APPS to 'App entity', which defined to be an 'agency' or 'organization' which means 'an individual (including a sole trader), a body corporate, a partnership, any other unincorporated association, or a trust, unless it is a small business operator, registered political party, State or Territory authority or a prescribed instrumentality of a State'.
- **New Zealand Privacy Act 1993:** 'Controller' is referred under The Privacy Act 1993 to 'agency', which means 'any person or body of persons, whether corporate or unincorporated, and whether in the public sector or the private sector; and, for the avoidance of doubt, includes a department'.

#### A.5 Processor

- **GDPR:** 'processor' means 'a natural or legal person, public authority, agency or other body which processes personal data on behalf of the controller';
- **PIPEDA:** 'Processor' is referred under PIPEDA to 'organizations'.
- **CCPA:** 'Processor' is referred under PIPEDA to 'business'.
- **APPs:** 'Processor' is referred under APPS to 'App entity', which defined to be an "agency" or "organization".

- **New Zealand Privacy Act 1993:** ‘Processor’ is referred under the Privacy Act 1993 to an ‘agency’.

## Appendix B RESULT

This section presents the result of a high-level comparison of various data protection laws, which are: General Data Protection Regulations (GDPR) [58], the Personal Information Protection and Electronic Documents Act (PIPEDA) [37, 42], California Consumer Privacy Act (CCPA) [22], Australian Privacy Principles (APPs) [28, 29], and the New Zealand Privacy Act (1993) [36, 39]. The analysis of the selected data protection laws is based on the principles and rights.

Table 9. Transparency Principle

**Definition:** *The organisation must provide detailed information on its policies and procedures concerning the management of personal information, and this must be readily available to the public.*

GDPR	Article 5 and Recital 39	<i>lawfulness, fairness and transparency</i>
	‘Personal data shall be processed lawfully, fairly and in a transparent manner in relation to the data subject’, where ‘(39) The principle of transparency requires that any information and communication relating to the processing of those personal data be easily accessible and easy to understand, and that clear and plain language be used’.	
PIPEDA	Principle 8	<i>Openness</i>
	‘An organization must make detailed information about its policies and practices relating to the management of personal information publicly and readily available’.	
CCPA	-	-
	Not mentioned explicitly as a principle or right, but it says in the introduction that: ‘Our desire for privacy controls and transparency in data practices is heightened’.	
APPS	App1	<i>Open and transparent management of personal information</i>
	‘Ensures that APP entities manage personal information in an open and transparent way. This includes having a clearly expressed and up to date APP privacy policy’.	
New Zealand	Principle 3	<i>Collection of information from subject</i>
	‘Agencies should be open when collecting information.... The best way to do this is usually with a clear privacy statement’.	

Table 10. Purpose Limitation Principle

**Definition:** *The purposes that the personal information is being collected and is used for must be shared by the organization, either prior to or at the time it is collected.*

GDPR	Article 5	<i>Purpose Limitation</i>
	'Personal data shall be collected for specified, explicit and legitimate purposes and not further processed in a manner that is incompatible with those purposes; further processing for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes shall, in accordance with Article 89(1), not be considered to be incompatible with the initial purposes';	
PIPEDA	Principle 2	<i>Identifying Purposes</i>
	'The purposes for which the personal information is being collected must be identified by the organization before or at the time of collection'.	
CCPA	1798.100. (b)	-
	'A business shall not collect additional categories of personal information or use personal information collected for additional purposes without providing the consumer with notice consistent with this section'.	
APPS	App 6	<i>Use or disclosure of personal information</i>
	6.12 'The purpose for which an APP entity collects personal information is known as the 'primary purpose' of collection. This is the specific function or activity for which the entity collects the personal information'.	
New Zealand	Principle 1	<i>Purpose for collection of personal information</i>
	'Agencies need to carefully consider the purpose for which they collect personal information'.	

Table 11. Limiting Use and Disclosure Principle

**Definition:** *An organisation may only use or disclose personal information for the purposes for which it was collected.*

GDPR	Article 5	<i>Purpose limitation</i>
	'Personal data shall be collected for specified, explicit and legitimate purposes and not further processed in a manner that is incompatible with those purposes; further processing for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes shall, in accordance with Article 89(1), not be considered to be incompatible with the initial purposes'	
PIPEDA	Principle 5	<i>Limiting Use, Disclosure, and Retention</i>
	'Unless the individual consents otherwise or it is required by law, personal information can only be used or disclosed for the purposes for which it was collected'.	
CCPA	1798.100. (b) and 1798.120.(b)	-
	1798.100. (b) 'A business shall not ..... use personal information collected for additional purposes without providing the consumer with notice consistent with this section'. 1798.120.(b) 'A business that sells consumers' personal information to third parties shall provide notice to consumers, pursuant to subdivision (a) of Section 1798.135, that this information may be sold and that consumers have the "right to opt-out" of the sale of their personal information'.	
APPs	App 6	<i>Use or disclosure of personal information</i>
	'An APP entity can only use or disclose personal information for a purpose for which it was collected (known as the 'primary purpose'), or for a secondary purpose if an exception applies'.	
New Zealand	Principle 10 - 11	<i>10 + 11: Limits on use and disclosure of personal information</i>
	P10: 'Agencies must use personal information for the same purpose for which they collected that information'. P11: 'Agencies can only disclose personal information in limited circumstances. One example is where another law requires them to disclose the information'.	

Table 12. Data Minimisation Principle

**Definition:** *Where personal data is required, it must be relevant, adequate and limited only to what is needed for the purpose stated.*

GDPR	Article 5	<i>Data Minimisation</i>
	'Personal data shall be adequate, relevant and limited to what is necessary in relation to the purposes for which they are processed'.	
PIPEDA	Principle 4	<i>Limiting Collection</i>
	'The collection of personal information must be limited to that which is needed for the purposes identified by the organization. Information must be collected by fair and lawful means'.	
CCPA	1798.100. (b)	-
	'A business shall not collect additional categories of personal information ... for additional purposes without providing the consumer with notice consistent with this section'.	
APPS	App 3	<i>Collection of solicited personal information</i>
	'An agency may collect personal information that is 'directly related to' one or more of the agency's functions or activities (APP 3.1). To be 'directly related to', a clear and direct connection must exist between the personal information being collected and an agency function or activity (APP 3.16)'.	
New Zealand	Principle 1	<i>Purpose for collection of personal information</i>
	'Personal information must only be collected when: the collection is for a lawful purpose, connected with what the agency does, and it's necessary to collect the information for that purpose'.	

Table 13. Consent Principle

**Definition:** *The individual's consent is required for the collection, use, and/or disclosure of their personal information.*

GDPR	Recital 11 - Article 7 – Article 8	<i>Conditions for consent - Conditions applicable to child's consent ...</i>
	'consent of the data subject means any freely given, specific, informed and unambiguous indication of the data subject's wishes by which he or she, by a statement or by a clear affirmative action, signifies agreement to the processing of personal data relating to him or her'; 'Where processing is based on consent, the controller shall be able to demonstrate that the data subject has consented to processing of his or her personal data'. 'Where the child is below the age of 16 years, such processing shall be lawful only if and to the extent that consent is given or authorised by the holder of parental responsibility over the child'.	
PIPEDA	Principle 3	<i>Consent</i>
	'Organizations are generally required to obtain meaningful consent for the collection, use and disclosure of personal information'. 'To make consent meaningful, people must understand what they are consenting to'. 'Consent and children: Obtain consent from a parent or guardian for any individual unable to provide meaningful consent themselves (the OPC takes the position that, in all but exceptional'	
CCPA	1798.120. (c) - 1798.120. (d)	-
	1798.120. (c) 'A business that has received direction from a consumer not to sell the consumer's personal information or, in the case of a minor consumer's personal information has not received consent to sell the minor consumer's personal information shall be prohibited, pursuant to paragraph (4) of subdivision (a) of Section 1798.135, from selling the consumer's personal information after its receipt of the consumer's direction, unless the consumer subsequently provides express authorization for the sale of the consumer's personal information'. 1798.120. (d) 'Notwithstanding subdivision (a), a business shall not sell the personal information of consumers if the business has actual knowledge that the consumer is less than 16 years of age, unless the consumer, in the case of consumers between 13 and 16 years of age, or the consumer's parent or guardian, in the case of consumers who are less than 13 years of age, has affirmatively authorized the sale of the consumer's personal information'.	
APPS	Chapter B	<i>Key concepts</i>
	B.35 'Consent means 'express consent or implied consent' (s 6(1)). The four key elements of consent are: the individual is adequately informed before giving consent, the individual gives consent voluntarily, the consent is current and specific, and the individual has the capacity to understand and communicate their consent'. B.48 'An APP entity should generally seek consent from an individual for collection and proposed uses and disclosures of personal information at the time the information is collected'. B.57 'As a general principle, an individual under the age of 18 has capacity to consent when they have sufficient understanding and maturity to understand what is being proposed. In some circumstances, it may be appropriate for a parent or guardian to consent on behalf of a young person'.	
New Zealand	Principle 3	<i>Collection of information from subject</i>
	N/A New Zealand's Privacy Act does not require the agency to obtain an individual's consent, however, 'agencies must take reasonable steps to ensure that the person they are collecting information from is aware'.	

Table 14. Lawfulness of processing Principle

**Definition:** *Personal information must be processed by fair and lawful means.*

GDPR	Article 6	<i>Lawfulness of Processing</i>
	'Processing shall be lawful only if and to the extent that at least one of the following applies: (a) the data subject has given consent to the processing of his or her personal data for one or more specific purposes; (b) processing is necessary for the performance of a contract to which the data subject is party or in order to take steps at the request of the data subject prior to entering into a contract; (c) processing is necessary for compliance with a legal obligation to which the controller is subject; (d) processing is necessary in order to protect the vital interests of the data subject or of another natural person; (e) processing is necessary for the performance of a task carried out in the public interest or in the exercise of official authority vested in the controller; (f) processing is necessary for the purposes of the legitimate interests pursued by the controller or by a third party, except where such interests are overridden by the interests or fundamental rights and freedoms of the data subject which require protection of personal data, in particular where the data subject is a child'.	
PIPEDA	Principle 4	<i>Limiting Collection</i>
	'Information must be collected by fair and lawful means. This requirement is intended to prevent organizations from collecting information by misleading or deceiving about the purpose'.	
CCPA	-	-
	Not mentioned explicitly, but it can be inferred from 1798.105. (d): 'A business or a service provider shall not be required to comply with a consumer's request to delete the consumer's personal information if it is necessary for the business or service provider to maintain the consumer's personal information in order to.....: (9) Otherwise use the consumer's personal information, internally, in a lawful manner that is compatible with the context in which the consumer provided the information'.	
APPS	App 3	<i>Collection of solicited personal information</i>
	'An APP entity must collect personal information 'only by lawful and fair means' (APP 3.5). This requirement applies to all APP entities'.	
New Zealand	Principle 4	<i>Manner of collection of personal information</i>
	'Personal information must not be collected by unlawful means or by means that are unfair or unreasonably intrusive in the circumstances'.	

Table 15. Accuracy Principle

**Definition:** *Attempts must be made to ensure that personal information is as accurate, complete and up-to-date as possible to ensure it satisfies the purposes for which it will be used.*

GDPR	Article 5	<i>Accuracy</i>
	Attempts must be made to ensure that personal information is as accurate, complete and up-to-date as possible to ensure it satisfies the purposes for which it will be used.	
PIPEDA	Principle 6	<i>Accuracy</i>
	'Personal information must be as accurate, complete, and up-to-date as possible in order to properly satisfy the purposes for which it is to be used'.	
CCPA	-	-
	N/A	
APPS	App 10	<i>Quality of personal information</i>
	'An APP entity must take reasonable steps to ensure the personal information it collects is accurate, up to date and complete. An entity must also take reasonable steps to ensure the personal information it uses or discloses is accurate, up to date, complete and relevant, having regard to the purpose of the use or disclosure'.	
New Zealand	Principle 8	<i>Accuracy, etc, of personal information to be checked before use</i>
	'Before it uses or discloses personal information, an agency must take reasonable steps to check that information is accurate, complete, relevant, up to date and not misleading'.	



Table 16. Storage Limitation Principle

**Definition:** *Personal information must not be stored for longer than necessary once it has met the purposes for which it was collected.*

GDPR	Article 5	<i>Storage limitation</i>
	'Personal data shall be kept in a form which permits identification of data subjects for no longer than is necessary for the purposes for which the personal data are processed; personal data may be stored for longer periods insofar as the personal data will be processed solely for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes in accordance with Article 89(1) subject to implementation of the appropriate technical and organisational measures required by this Regulation in order to safeguard the rights and freedoms of the data subject'.	
PIPEDA	Principle 5	<i>Limiting Use, Disclosure, and Retention</i>
	'Personal information must only be kept as long as required to serve those purposes. Destroy, erase or anonymise any personal information that your organization no longer needs'.	
CCPA	1798.140.	-
	Not mentioned as a requirement for the businesses, however, Service provider and third party are '[prohibited] from retaining, using, or disclosing the personal information for any purpose other than for the specific purpose of performing the services specified in the contract for the business'.	
APPS	App 11	<i>Security of personal information</i>
	11.3 'An APP entity must take reasonable steps to destroy or de-identify the personal information it holds once the personal information is no longer needed for any purpose for which the personal information may be used or disclosed under the APPs'.	
New Zealand	Principle 9	<i>Agency not to keep personal information for longer than necessary</i>
	'An agency that holds personal information must not keep that information for longer than is necessary for the purposes for which the information may be lawfully used'.	

Table 17. Security Principle

**Definition:** *Safeguarding procedures must be in place to protect personal information and prevent its loss, misuse or disclosure.*

GDPR	Article 5 – Article 33	<i>integrity and confidentiality - Notification of a personal data breach ...</i>
	'Personal data shall be processed in a manner that ensures appropriate security of the personal data, including protection against unauthorised or unlawful processing and against accidental loss, destruction or damage, using appropriate technical or organisational measures. 'In the case of a personal data breach the controller shall without undue delay and, where feasible, not later than 72 hours after having become aware of it notify the personal data breach to the supervisory authority'.	
PIPEDA	Principle 7	<i>Safeguards - What you need to know about mandatory reporting of breaches ...</i>
	'Personal information must be protected by appropriate security relative to the sensitivity of the information'. 'Organizations subject to the (PIPEDA) will be required to: report to the Privacy Commissioner of Canada breaches of security safeguards involving personal information that pose a real risk of significant harm to individuals, notify affected individuals about those breaches, and keep records of all breaches' [41]	
CCPA	-	-
	Not mentioned explicitly, but it can be inferred from 1798.140. (h) (1) that business that uses deidentified information must have "implemented technical safeguards that prohibit reidentification of the consumer to whom the information may pertain." Existing law requires a business or person that suffers a breach of security of computerized data that includes personal information, as defined, to disclose that breach, as specified.	
APPS	App 11	<i>Security of personal information - Australian entities and the EU GDPR</i>
	'An APP entity must take reasonable steps to protect personal information it holds from misuse, interference and loss, and from unauthorized access, modification or disclosure. An entity has obligations to destroy or de-identify personal information in certain circumstances'. 'A notifiable data breaches scheme requires APP entities to provide a statement to the Commissioner notifying of an eligible data breach as soon as practicable after the entity becomes aware of the breach. It also requires entities to notify affected individuals as soon as practicable after preparing the statement for the Commissioner'[30].	
New Zealand	Principle 5	<i>Storage and security of personal information - Do we have to report data breaches?</i>
	'It's impossible to stop all mistakes. But agencies must ensure that there are reasonable safeguards in place to prevent loss, misuse or disclosure of personal information'. 'Breach notification is voluntary but that is likely that will change with privacy law reform. The Government has indicated that a mandatory requirement to report data breaches is going to be part of the changes made in a new Privacy Act' [34].	

Table 18. Accountability Principle

**Definition:** *An organisation is responsible for complying with all data protection laws concerning the personal information that is under its control, and it must appoint someone to be accountable for complying with the law in this area.*

GDPR	Article 24 - Article 37	<i>Accountability - Designation of the data protection officer</i>
	'The controller shall be responsible for, and be able to demonstrate compliance with, [law]. 'The controller and the processor shall designate a data protection officer [in any of the specified cases]'	
PIPEDA	Principle 1	<i>Accountability</i>
	'An organization is responsible for personal information under its control. It must appoint someone to be accountable for its compliance with these fair information principles'. 'The Privacy Officer should establish a program that demonstrates compliance by mapping the program to applicable legislation'.	
CCPA	1798.155. (a)	-
	'Any business or third party may seek the opinion of the Attorney General for guidance on how to comply with the provisions of this title'.	
APPS	App 1	<i>Open and transparent management of personal information</i>
	1.4 'An APP entity must take reasonable steps to implement practices, procedures and systems that will ensure it complies with the APPs and any binding registered APP code, and is able to deal with related inquiries and complaints'. 10: 'Privacy Officer: An agency must, at all times, have a designated Privacy Officer. An agency may have more than one Privacy Officer'.	
New Zealand	-	<i>23 Privacy Officer</i>
	'It shall be the responsibility of each agency to ensure that there are, within that agency, 1 or more individuals whose responsibilities include: (a) the encouragement of compliance, by the agency, with the information privacy principles. (b) dealing with requests made to the agency pursuant to this Act. (c) working with the Commissioner in relation to investigations conducted pursuant to Part 8 in relation to the agency. (d) otherwise ensuring compliance by the agency with the provisions of this Act'.	

Table 19. Anonymity and Pseudonymity Principle

**Definition:** *Individuals must be given the option of not identifying themselves, or the choice of using a pseudonym, in relation to certain matters.*

GDPR	Article 32	<i>Security of processing</i>
	Not mentioned for the purpose of dealing with an organisation, but mentioned under security of processing: 'the controller and the processor shall implement appropriate technical and organisational measures to ensure a level of security appropriate to the risk, including inter alia as appropriate: (a) the pseudonymisation and encryption of personal data'	
PIPEDA	-	-
	Not mentioned for the purpose of dealing with an organisation, but mentioned in the case and principles of storage limitation: 'Destroy, erase or anonymise any personal information that your organization no longer needs'.	
CCPA	1798.140	-
	It is not mentioned clearly, however, the CCPA referred the 'Pseudonymise' or 'Pseudonymisation' to 'the processing of personal information in a manner that renders the personal information no longer attributable to a specific consumer without the use of additional information, provided that the additional information is kept separately and is subject to technical and organizational measures to ensure that the personal information is not attributed to an identified or identifiable consumer'.	
APPS	App 2	<i>Anonymity and pseudonymity</i>
	'App2 Requires APP entities to give individuals the option of not identifying themselves, or of using a pseudonym'.	
New Zealand	-	-
	N/A	

Table 20. Source Principle

**Definition:** *Unless there is an exception, personal information must be collected from the person the information is about.*

GDPR	Article 14	<i>Information to be provided where personal data have not been obtained from the data subject</i>
	2. '...', the controller shall provide the data subject with the following information necessary to ensure fair and transparent processing in respect of the data subject: ... (f) from which source the personal data originate, and if applicable, whether it came from publicly accessible sources';	
PIPEDA	Principle 4	<i>Limiting Collection</i>
	'Upon request, an organization shall inform an individual whether or not the organization holds personal information about the individual. Organizations are encouraged to indicate the source of this information'.	
CCPA	1798.110. (a)	-
	'A consumer shall have the right to request that a business that collects personal information about the consumer disclose to the consumer the following: (2) The categories of sources from which the personal information is collected'.	
APPS	App 3	<i>Collection of solicited personal information</i>
	'An organisation must, on request, provide its source for an individual's personal information, unless it is impracticable or unreasonable to do so. APP 3.6 provides that an APP entity 'must collect personal information about an individual only from the individual', unless exceptions apply'.	
New Zealand	Principle 2	<i>Source of personal information</i>
	'Personal information must usually be collected from the person the information is about. Collecting information from the person concerned means that people know what is going on and have some control over their information'.	

Table 21. Cross-border Disclosure of Personal Information Principle

**Definition:** *Individuals' information is expected to be protected and handled appropriately, wherever the processing takes place.*

GDPR	Article 44	<i>General principle for transfers</i>
	'All provisions in this Chapter "Chapter V: Transfers of personal data to third countries or international organisations" shall be applied in order to ensure that the level of protection of natural persons guaranteed by this Regulation is not undermined'.	
PIPEDA	-	<i>Personal information transferred across borders</i>
	'Individuals should expect that their information is protected and handled appropriately, regardless of where it's processed'.	
CCPA	-	-
	N/A 1798.145. (a) 'The obligations imposed on businesses by this title shall not restrict a business's ability to: ... (6) Collect or sell a consumer's personal information if every aspect of that commercial conduct takes place wholly outside of California. For purposes of this title, commercial conduct takes place wholly outside of California if the business collected that information while the consumer was outside of California, no part of the sale of the consumer's personal information occurred in California, and no personal information collected while the consumer was in California is sold. This paragraph shall not permit a business from storing personal information about a consumer when the consumer is in California and then collecting that personal information when the consumer and stored personal information is outside of California'.	
APPS	App 8	<i>Cross-border disclosure of personal information</i>
	'Before an APP entity discloses personal information to an overseas recipient, the entity must take reasonable steps to ensure that the overseas recipient does not breach the APPs in relation to the information'.	
New Zealand	-	<i>Does the Privacy Act apply to organisations based overseas?</i>
	'Any organisation operating in New Zealand is required to comply with the Privacy Act, regardless of where the organisation is based'.	

Table 22. Dealing with Unsolicited Personal Information Principle

**Definition:** *An organisation must take reasonable steps to manage unsolicited personal information. Unsolicited personal information is 'personal information received by an entity that has not been requested by that entity.'*

GDPR	-	-
	N/A	
PIPEDA	-	-
	N/A	
CCPA	-	-
	N/A	
APPS	App 4	<i>Dealing with unsolicited personal information</i>
	4.1 'APP 4 outlines the steps an APP entity must take if it receives unsolicited personal information. Unsolicited personal information is personal information received by an entity that has not been requested by that entity'. 4.2 An APP entity that receives unsolicited personal information must decide whether or not it could have collected the information under APP 3. If not, the entity must destroy or de-identify the information'.	
New Zealand	-	-
	N/A	

Table 23. Adoption, Use or Disclosure of an identifier Principle

**Definition:** *Adopting, using, or disclosing a unique identifier that was created for an individual for a different purpose should be prohibited.*

GDPR	Article 87	<i>Processing of the national identification number</i>
	'Member States may further determine the specific conditions for the processing of a national identification number or any other identifier of general application. In that case the national identification number or any other identifier of general application shall be used only under appropriate safeguards for the rights and freedoms of the data subject pursuant to this Regulation'.	
PIPEDA	-	<i>Guidelines for identification and authentication</i>
	'It is also important to avoid, where ever possible, using numbers such as a driver's licence number or social insurance number as an identifier as they were created for different purposes'.	
CCPA	-	-
	N/A	
APPS	App 9	<i>Adoption, Use or Disclosure of an identifier</i>
	'An organisation must not adopt, use or disclose a government related identifier unless an exception applies'.	
New Zealand	Principle 12	<i>Unique Identifiers</i>
	(2) 'An agency shall not assign to an individual a unique identifier that, to that agency's knowledge, has been assigned to that individual by another agency, unless those 2 agencies are associated persons within the meaning of section OD7 of the Income Tax Act 2004'.	

Table 24. Right of Individuals to Exercise their Rights

**Definition:** *Individuals shall have the right to exercise their data protection rights.*

GDPR	Article 12	<i>Transparent information, communication and modalities ...</i>
	'The controller shall facilitate the exercise of data subject rights under Articles 15 to 22. In the cases referred to in Article 11(2), the controller shall not refuse to act on the request of the data subject for exercising his or her rights'.	
PIPEDA	Principle 9	<i>Individual Access</i>
	'Help people prepare their request for access to personal information.' 'Respond to the request as quickly as possible, and no later than 30 days after receiving it'.	
CCPA	1798.130. (a)	-
	'A business shall: (1) Make available to consumers two or more designated methods for submitting requests for information required to be disclosed pursuant to Sections 1798.110 and 1798.115, including, at a minimum, a toll-free telephone number, and if the business maintains an Internet Web site, a Web site address. (2) Disclose and deliver the required information to a consumer free of charge within 45 days of receiving a verifiable request from the consumer.'	
APPS	Your Privacy Rights – App 12	<i>Access your personal information - Access to personal information</i>
	'An organisation or agency must be satisfied the request came from you or a person you authorised'. 'An agency must respond to a request for access to/ [correct] personal information within 30 days'. 'an entity cannot require an individual to follow a particular procedure, use a designated form or explain the reason for making the request. Any recommended procedure should be regularly reviewed to ensure that it is flexible and facilitates rather than hinders access'.	
New Zealand	Principle 6	<i>Access to personal information</i>
	'When an agency receives a request for access or correction, it has to do various things. It has to: decide whether it agrees to the request; if so, decide how it will provide access or correction; The agency has to make these decisions and let the requester know as soon as it can. The longest the agency can usually take is 20 working days from the date it receives the request.'	

Table 25. Right to be Informed

**Definition:** *Individuals must be informed about the collection, use and/or disclosure of their personal information.*

GDPR	Article 13 - 14	<i>Information to be provided where personal data are collected/ not obtained from the data subject</i>
	'Where personal data relating to a data subject are collected from the data subject, the controller shall, at the time when personal data are obtained, provide the data subject with all of the [specified] information', such as information about the controller, the purpose of processing, the recipients of the personal data, and the rights of the data subject...etc. 'Where personal data have not been obtained from the data subject, the controller shall provide the data subject with the [specified] information.'	
PIPEDA	Principle 3	<i>Consent</i>
	'The knowledge of the individual is required for the collection, use, or disclosure of personal information'.	
CCPA	1798.100 (b)	-
	'A business that collects a consumer's personal information shall, at or before the point of collection, inform consumers as to the categories of personal information to be collected and the purposes for which the categories of personal information shall be used'.	
APPS	App 5	<i>Notification of the collection of personal information</i>
	'An APP entity that collects personal information about an individual must take reasonable steps either to notify the individual of certain matters or to ensure the individual is aware of those matters'.	
New Zealand	Principle 3	<i>Collection of information from subject</i>
	'When an agency collects personal information from the person the information is about, it has to take reasonable steps to make sure that person knows things like: - why it's being collected - who will get the information - whether the person has to give the information or whether this is voluntary ... etc.'	



Table 26. Right of Individuals Access

**Definition:** *Individuals have the right to access the personal information which an organisation is holding about them.*

GDPR	Article 15	<i>Right of access by the data subject</i>
	'The data subject shall have the right to access to the personal data', and provide information about the processing, such as 'purposes of processing, categories of personal data concerned, recipients, etc.)'.	
PIPEDA	Principle 9	<i>Individual Access</i>
	'Individuals have a right to access the personal information that an organization holds about them'. 'When asked, advise people about the personal information about them your organization holds. Explain how that information is or has been used and to whom it has been disclosed. Give people access to their information at minimal or no cost or explain your reasons for not providing access. Providing access can take different forms. For example, you may provide a written or electronic copy of the information or allow the individual to view the information or listen to a recording of the information'.	
CCPA	1798.100. (d)	-
	'A business that receives a verifiable consumer request from a consumer to access personal information shall promptly take steps to disclose and deliver, free of charge to the consumer ... the categories and specific pieces of personal information the business has collected'.	
APPS	App 12	<i>Access to personal information</i>
	'APP 12 requires an APP entity that holds personal information about an individual to give the individual access to that information on request' 'The manner of access may, for example, be by email, by phone, in person, hard copy, or an electronic record'. 'An agency cannot impose upon an individual any charge for providing access to personal information'.	
New Zealand	Principle 6	<i>Access to personal information</i>
	'People usually have a right to ask for access to personal information that identifies them' '... a public sector agency shall not require the payment, by or on behalf of any individual who wishes to make an information privacy request'.	

Table 27. Right to Rectification

**Definition:** *Individuals shall have the right to ask for correction of their personal data.*

GDPR	Article 16	<i>Right to rectification</i>
	'The data subject shall have the right to obtain from the controller without undue delay the rectification of inaccurate personal data concerning him or her'.	
PIPEDA	Principle 9	<i>Individual Access</i>
	'Individuals have the right to challenge the accuracy and completeness of the information, and have that information amended as appropriate'.	
CCPA	-	-
	N/A	
APPS	App 13	<i>Correction of personal information</i>
	'Australian privacy law gives you the right to correct the personal information an organization or agency holds about you if it is: inaccurate, out of date, incomplete, irrelevant, misleading'.	
New Zealand	Principle 7	<i>Correction of personal information</i>
	'People have a right to ask the agency to correct information about themselves, if they think it is wrong'.	

Table 28. Right to Erasure

**Definition:** *Individuals shall have the right to ask for deletion of their personal data.*

GDPR	Article 17	<i>Right to erasure ('right to be forgotten')</i>
	'The data subject shall have the right to obtain from the controller the erasure of personal data concerning him or her without undue delay and the controller shall have the obligation to erase personal data without undue delay where [one of the specified grounds applies]'.	
PIPEDA	Principle 5 - Principle 6	<i>Principle 5 - Limiting Use, Disclosure, and Retention Principle 6- Accuracy</i>
	'Destroy, erase or anonymise any personal information that your organization no longer needs'. 'When an individual successfully demonstrates the inaccuracy or incompleteness of personal information, the organization shall amend the information as required. Depending upon the nature of the information challenged, amendment involves the correction, deletion, or addition of information'[27] .	
CCPA	1798.105. (a)	-
	'A consumer shall have the right to request that a business delete any personal information about the consumer which the business has collected from the consumer'.	
APPS	-	<i>Australian entities and the EU General Data Protection Regulation (GDPR)</i>
	'There is no equivalent 'right to erasure' under the Privacy Act, however APP 11.2 requires an APP entity that holds personal information to take reasonable steps to destroy the information or to ensure it is de-identified if the information is no longer needed for any purpose permitted under the Privacy Act' [30].	
New Zealand	Principle 9	<i>Agency not to keep personal information for longer than necessary</i>
	There is no equivalent 'right to erasure' under the New Zealand's Privacy Act, however, 'an agency that holds personal information must not keep that information for longer than is necessary for the purposes for which the information may be lawfully used'.	

Table 29. Right to Restriction of Processing

**Definition:** *Individuals shall have the right to restrict the processing of their personal data.*

GDPR	Article 18	<i>Right to restriction of processing</i>
	'The data subject shall have the right to obtain from the controller restriction of processing where [one of the specified cases applies]'.	
PIPEDA	-	-
	N/A	
CCPA	-	-
	N/A	
APPS	-	-
	N/A	
New Zealand	-	-
	N/A	

Table 30. Right to Object

**Definition:** *Individuals shall have the right to object to the processing of their personal data.*

GDPR	Article 21	<i>Right to Object</i>
	‘The data subject shall have the right to object, on grounds relating to his or her particular situation, at any time to processing of personal data concerning him or her’.	
PIPEDA	Principle 3	<i>Consent</i>
	There is no specific right to object to processing under the PIPEDA, but it can be inferred from principle 3 that ‘individuals can withdraw consent at any time, subject to legal or contractual restrictions and reasonable notice, and organizations must inform individual of the implications of withdrawal’.	
CCPA	1798.120. (a)	-
	‘A consumer shall have the right, at any time, to direct a business that sells personal information about the consumer to third parties not to sell the consumer’s personal information. This right may be referred to as the right to opt out’.	
APPS	Chapter B	<i>B.51 Key concepts</i>
	There is no specific right to object to processing under the APPs, but ‘An individual may withdraw their consent at any time’ [3]	
New Zealand	-	<i>When does a privacy waiver expire?</i>
	N/A The New Zealand’s Privacy Act does not contain an equivalent right to ‘right to object’. However, ‘an individual might at any point withdraw that consent and the agency has to respond accordingly’.	

Table 31. Right to Object to Marketing

**Definition:** *Individuals shall have the right to reject the processing of their personal data for direct marketing purposes.*

GDPR	Article 21	<i>Right to object</i>
	2. ‘Where personal data are processed for direct marketing purposes, the data subject shall have the right to object at any time to processing of personal data concerning him or her for such marketing, which includes profiling to the extent that it is related to such direct marketing’. 3. ‘Where the data subject objects to processing for direct marketing purposes, the personal data shall no longer be processed for such purposes’.	
PIPEDA	-	-
	N/A	
CCPA	1798.120. (c)	-
	It is not mentioned explicitly but could be inferred from 1798.120. (c), ‘a business that has received direction from a consumer not to sell the consumer’s personal information or, in the case of a minor consumer’s personal information has not received consent to sell the minor consumer’s personal information shall be prohibited, pursuant to paragraph (4) of subdivision (a) of Section 1798.135, from selling the consumer’s personal information after its receipt of the consumer’s direction, unless the consumer subsequently provides express authorization for the sale of the consumer’s personal information’.	
APPS	App 7	<i>Direct marketing</i>
	‘An organisation must not use or disclose the personal information that it holds about an individual for the purpose of direct marketing (APP 7.1) 7.2 and 7.3 require an organisation to provide a simple means by which an individual can request not to receive direct marketing communications (also known as ‘opting out’)’.	
New Zealand	-	-
	N/A	

Table 32. Right to Data Portability

**Definition:** *Individuals shall have the right to receive their personal data in a readily useable format that allows the Individual to transmit the information to another organisation.*

GDPR	Article 20	<i>Right to data Portability</i>
	‘The data subject shall have the right to receive the personal data concerning him or her, which he or she has provided to a controller, in a structured, commonly used and machine-readable format and have the right to transmit those data to another controller without hindrance from the controller to which the personal data have been provided’.	
PIPEDA	-	-
	N/A	
CCPA	1798.100. (d)	-
	‘A business that receives a verifiable consumer request from a consumer to access personal information shall promptly take steps to disclose and deliver, free of charge to the consumer, the personal information required by this section. The information may be delivered by mail or electronically, and if provided electronically, the information shall be in a portable and, to the extent technically feasible, in a readily useable format that allows the consumer to transmit this information to another entity without hindrance’.	
APPS	-	<i>Australian entities and the EU General Data Protection Regulation (GDPR)</i>
	N/A ‘The Privacy Act does not include an equivalent right to ‘data portability’ or ‘right to object’. However, individuals do have a right to request access to, and correction of, their personal information under APPs 12 and 13. In giving access under APP 12, where reasonable and practicable, an entity must give access in the manner requested by the individual. For more information, see Chapters 12 and 13 of the APP guidelines’ [30].	
New Zealand	-	-
	N/A	

Table 33. Right to Object to Automated Decision-Making

**Definition:** *Individuals must have the right to object to a decision that is based solely on automated processing.*

GDPR	Article 22	<i>Automated individual decision-making, including profiling</i>
	‘The data subject shall have the right not to be subject to a decision based solely on automated processing, including profiling, which produces legal effects concerning him or her or similarly significantly affects him or her’.	
PIPEDA	-	-
	N/A	
CCPA	-	-
	N/A	
APPS	-	-
	N/A	
New Zealand	-	-
	N/A	

Table 34. Right to Withdraw Consent

**Definition:** *Individuals shall have the right to withdraw consent at any time.*

GDPR	Article 7	<i>Conditions for consent</i>
	'The data subject shall have the right to withdraw his or her consent at any time. The withdrawal of consent shall not affect the lawfulness of processing based on consent before its withdrawal. Prior to giving consent, the data subject shall be informed thereof. It shall be as easy to withdraw as to give consent'.	
PIPEDA	Principle 3	<i>Consent</i>
	'Individuals can withdraw consent at any time, subject to legal or contractual restrictions and reasonable notice, and you must inform individual of the implications of withdrawal'.	
CCPA	1798.120. (a)	-
	'A consumer shall have the right, at any time, to direct a business that sells personal information about the consumer to third parties not to sell the consumer's personal information. This right may be referred to as the right to opt out'.	
APPS	Chapter B	<i>B.51 Key concepts</i>
	'An individual may withdraw their consent at any time, and this should be an easy and accessible process. Once an individual has withdrawn consent, an APP entity can no longer rely on that past consent for any future use or disclosure of the individual's personal information' [31]	
New Zealand	-	<i>When does a privacy waiver expire?</i>
	'An individual might at any point withdraw that consent and the agency has to respond accordingly' [32].	

Table 35. Right to Complain

**Definition:** *Every data subject shall have the right to lodge a complaint.*

GDPR	Article 14	<i>Transparent information, communication and modalities for the exercise of the rights ...</i>
	‘If the controller does not take action on the request of the data subject, the controller shall inform the data subject without delay and at the latest within one month of receipt of the request of the reasons for not taking action and on the possibility of lodging a complaint with a supervisory authority and seeking a judicial remedy’.	
PIPEDA	Principle 10	<i>Challenging Compliance - File a formal privacy complaint</i>
	‘An individual must be able to challenge your organization’s compliance with the fair information principles. They should address their challenge to the person in your organization who is accountable for compliance with PIPEDA’. ‘If you can’t resolve the issue directly with the organization, you may decide to file a formal complaint’.	
CCPA	1798.150. (a)	-
	‘(1) Any consumer whose nonencrypted or nonredacted personal information is subject to an unauthorized access and exfiltration, theft, or disclosure as a result of the business’ violation of the duty to implement and maintain reasonable security procedures and practices appropriate to the nature of the information to protect the personal information may institute a civil action for any of [specified conditions]’. ..... ‘(2) A consumer bringing an action as defined in paragraph (1) of subdivision (c) shall notify the Attorney General within 30 days that the action has been filed. (3) The Attorney General, upon receiving such notice shall, within 30 days, do one of the specified steps’.	
APPS	-	<i>Lodge a privacy complaint with us</i>
	‘If you’re concerned your personal information has been mishandled, you first need to complain to the organisation or agency you think has mishandled it. If they don’t respond to your complaint within 30 days or you’re not happy with their response, you can lodge a complaint with us’.	
New Zealand	Your Rights	<i>Making a complaint</i>
	‘If you’re unable to resolve a privacy dispute, you can make a complaint to us. But, before you make a complaint to us, contact the agency and let it know what the problem is. Agencies can often sort out problems more quickly without the need for us to get involved’.	

Table 36. Right of individuals not to be Discriminated

**Definition:** *A business shall not discriminate against a consumer because the consumer exercised any of their rights.*

GDPR	-	-
	N/A	
PIPEDA	-	-
	N/A	
CCPA	1798.130. (a)	-
	“1798.125. (a) (1) A business shall not discriminate against a consumer because the consumer exercised any of the consumer’s rights under this title.”	
APPS	-	-
	N/A	
New Zealand	-	-
	N/A	

## Appendix C PRIVACY BY DESIGN SCHEMES

This section presents various Privacy by Design (PbD) schemes (e.g., privacy principles, strategies, guidelines, and patterns) that developed previously by different researchers.

### C.1 Privacy Principles

*C.1.1 Privacy by Design Principles by Cate (2010).* Fair Information Practice Principles (FIPPs) [9].

**01. Notice / Awareness** Consumers should be given notice of an entity's information practices before any personal information is collected from them. This requires that companies explicitly notify some or all of the following:

- Identification of the entity collecting the data;
- Identification of the uses to which the data will be put;
- Identification of any potential recipients of the data;
- The nature of the data collected and the means by which it is collected;
- Whether the provision of the requested data is voluntary or required;
- The steps taken by the data collector to ensure the confidentiality, integrity and quality of the data.

**02. Choice / Consent** Choice and consent in an on-line information-gathering sense means giving consumers options to control how their data is used. Specifically, choice relates to secondary uses of information beyond the immediate needs of the information collector to complete the consumer's transaction. The two typical types of choice models are 'opt-in' or 'opt-out.' The 'opt-in' method requires that consumers affirmatively give permission for their information to be used for other purposes. Without the consumer taking these affirmative steps in an 'opt-in' system, the information gatherer assumes that it cannot use the information for any other purpose. The 'opt-out' method requires consumers to affirmatively decline permission for other uses. Without the consumer taking these affirmative steps in an 'opt-out' system, the information gatherer assumes that it can use the consumer's information for other purposes. Each of these systems can be designed to allow an individual consumer to tailor the information gatherer's use of the information to fit their preferences by checking boxes to grant or deny permission for specific purposes rather than using a simple "all or nothing" method.

**03. Access / Participation** Access as defined in the Fair Information Practice Principles includes not only a consumer's ability to view the data collected, but also to verify and contest its accuracy. This access must be inexpensive and timely in order to be useful to the consumer.

**04. Integrity / Security** Information collectors should ensure that the data they collect is accurate and secure. They can improve the integrity of data by cross-referencing it with only reputable databases and by providing access for the consumer to verify it. Information collectors can keep their data secure by protecting against both internal and external security threats. They can limit access within their company to only necessary employees to protect against internal threats, and they can use encryption and other computer-based security systems to stop outside threats

**05. Enforcement / Redress** In order to ensure that companies follow the Fair Information Practice Principles, there must be enforcement measures. The FTC identified three types of enforcement measures: self-regulation by the information collectors or an appointed regulatory body; private remedies that give civil causes of action for individuals whose information has been misused to sue violators; and government enforcement that can include civil and criminal penalties levied by the government.

*C.1.2 Privacy by Design Principles by Ann Cavoukian (2010).* Cavoukian (2010) has proposed seven Privacy by Design foundation principles [10].

**01. Proactive not Reactive; Preventative not Remedial** The Privacy by Design (PbD) approach is characterized by proactive rather than reactive measures. It anticipates and prevents privacy invasive events before they happen. PbD does not wait for privacy risks to materialize, nor does it offer remedies for resolving privacy infractions once they have occurred - it aims to prevent them from occurring. In short, Privacy by Design comes before-the-fact, not after.

**02. Privacy as the Default Setting** We can all be certain of one thing - the default rules! Privacy by Design seeks to deliver the maximum degree of privacy by ensuring that personal data are automatically protected in any given IT system or business practice. If an individual does nothing, their privacy still remains intact. No action is required on the part of the individual to protect their privacy - it is built into the system, by default. 03. Privacy Embedded into Design Privacy by Design is embedded into the design and architecture of IT systems and business practices. It is not bolted on as an add-on, after the fact. The result is that privacy becomes an essential component of the core functionality being delivered. Privacy is integral to the system, without diminishing functionality.

**03. Privacy Embedded into Design** Privacy by Design is embedded into the design and architecture of IT systems and business practices. It is not bolted on as an add-on, after the fact. The result is that privacy becomes an essential component of the core functionality being delivered. Privacy is integral to the system, without diminishing functionality.

**04. Full Functionality-Positive - Sum, not Zero-Sum** Privacy by Design seeks to accommodate all legitimate interests and objectives in a positive-sum "win-win" manner, not through a dated, zero-sum approach, where unnecessary trade-offs

are made. Privacy by Design avoids the pretense of false dichotomies, such as privacy vs. security, demonstrating that it is possible to have both.

**05. End-to-End Security - Full Lifecycle Protection** Privacy by Design, having been embedded into the system prior to the first element of information being collected, extends securely throughout the entire lifecycle of the data involved - strong security measures are essential to privacy, from start to finish. This ensures that all data are securely retained, and then securely destroyed at the end of the process, in a timely fashion. Thus, Privacy by Design ensures cradle to grave, secure lifecycle management of information, end-to-end.

**06. Visibility and Transparency - Keep it Open** Privacy by Design seeks to assure all stakeholders that whatever the business practice or technology involved, it is in fact, operating according to the stated promises and objectives, subject to independent verification. Its component parts and operations remain visible and transparent, to users and providers alike. Remember, trust but verify.

**07. Respect for User Privacy - Keep it User-Centric** Above all, Privacy by Design requires architects and operators to keep the interests of the individual uppermost by offering such measures as strong privacy defaults, appropriate notice, and empowering user-friendly options. Keep it user-centric.

### C.1.3 ISO 29100 Privacy framework . ISO 29100 has proposed 11 privacy principles [57]

#### 01. Consent and choice Adhering to the consent principle means:

- presenting to the PII principal the choice whether or not to allow the processing of their PII except where the PII principal cannot freely withhold consent or where applicable law specifically allows the processing of PII without the natural person's consent. The PII principal's choice must be given freely, specific and on a knowledgeable basis;
- obtaining the opt-in consent of the PII principal for collecting or otherwise processing sensitive PII except where applicable law allows the processing of sensitive PII without the natural person's consent;
- informing PII principals, before obtaining consent, about their rights under the individual participation and access principle;
- providing PII principals, before obtaining consent, with the information indicated by the openness, transparency and notice principle; and
- explaining to PII principals the implications of granting or withholding consent.

#### 02. Purpose legitimacy and specification Adhering to the purpose legitimacy and specification principle means:

- ensuring that the purpose(s) complies with applicable law and relies on a permissible legal basis;
- communicating the purpose(s) to the PII principal before the time the information is collected or used for the first time for a new purpose;
- using language for this specification which is both clear and appropriately adapted to the circumstances; and
- if applicable, giving sufficient explanations for the need to process sensitive PII.

#### 03. Collection limitation Adhering to the collection limitation principle means:

- limiting the collection of PII to that which is within the bounds of applicable law and strictly necessary for the specified purpose(s).

**04. Data minimisation** Adhering to the Data Minimisation principle means designing and implementing data processing procedures and ICT systems in such a way as to:

- minimise the PII which is processed and the number of privacy stakeholders and people to whom PII is disclosed or who have access to it;
- ensure adoption of a "need-to-know" principle, i.e. one should be given access only to the PII which is necessary for the conduct of his/her official duties in the framework of the legitimate purpose of the PII processing;
- use or offer as default options, wherever possible, interactions and transactions which do not involve the identification of PII principals, reduce the observability of their behaviour and limit the linkability of the PII collected; and
- delete and dispose of PII whenever the purpose for PII processing has expired, there are no legal requirements to keep the PII or whenever it is practical to do so.

#### 05. Use, retention and disclosure limitation Adhering to the use, retention and disclosure limitation principle means:

- Limiting the use, retention and disclosure (including transfer) of PII to that which is necessary in order to fulfil specific, explicit and legitimate purposes;
- Limiting the use of PII to the purposes specified by the PII controller prior to collection, unless a different purpose is explicitly required by applicable law;
- Retaining PII only as long as necessary to fulfil the stated purposes, and thereafter securely destroying or anonymising it; and
- Locking (i.e. archiving, securing and exempting the PII from further processing) any PII when and for as long as the stated purposes have expired, but where retention is required by applicable laws.



**06. Accuracy and quality** Adhering to the accuracy and quality principle means:

- ensuring that the PII processed is accurate, complete, up-to-date (unless there is a legitimate basis for keeping outdated data), adequate and relevant for the purpose of use;
- ensuring the reliability of PII collected from a source other than from the PII principal before it is processed;
- verifying, through appropriate means, the validity and correctness of the claims made by the PII principal prior to making any changes to the PII (in order to ensure that the changes are properly authorized), where it is appropriate to do so;
- establishing PII collection procedures to help ensure accuracy and quality; and
- establishing control mechanisms to periodically check the accuracy and quality of collected and stored PII.

**07. Openness, transparency and notice** Adhering to the openness, transparency and notice principle means:

- providing PII principals with clear and easily accessible information about the PII controller's policies, procedures and practices with respect to the processing of PII;
- including in notices the fact that PII is being processed, the purpose for which this is done, the types of privacy stakeholders to whom the PII might be disclosed, and the identity of the PII controller including information on how to contact the PII controller;
- disclosing the choices and means offered by the PII controller to PII principals for the purposes of limiting the processing of, and for accessing, correcting and removing their information; and
- giving notice to the PII principals when major changes in the PII handling procedures occur.

**08. Individual participation and access;** Adhering to the individual participation and access principle means:

- giving PII principals the ability to access and review their PII, provided their identity is first authenticated with an appropriate level of assurance and such access is not prohibited by applicable law;
- allowing PII principals to challenge the accuracy and completeness of the PII and have it amended, corrected or removed as appropriate and possible in the specific context;
- providing any amendment, correction or removal to PII processors and third parties to whom personal data had been disclosed, where they are known; and
- establishing procedures to enable PII principals to exercise these rights in a simple, fast and efficient way, which does not entail undue delay or cost.

**09. Accountability** The processing of PII entails a duty of care and the adoption of concrete and practical measures for its protection. Adhering to the accountability principle means:

- documenting and communicating as appropriate all privacy-related policies, procedures and practices;
- assigning to a specified individual within the organization (who might in turn delegate to others in the organization as appropriate) the task of implementing the privacy-related policies, procedures and practices;
- when transferring PII to third parties, ensuring that the third party recipient will be bound to provide an equivalent level of privacy protection through contractual or other means such as mandatory internal policies (applicable law can contain additional requirements regarding international data transfers);
- providing suitable training for the personnel of the PII controller who will have access to PII;
- setting up efficient internal complaint handling and redress procedures for use by PII principals;
- informing PII principals about privacy breaches that can lead to substantial damage to them (unless prohibited, e.g., while working with law enforcement) as well as the measures taken for resolution;
- notifying all relevant privacy stakeholders about privacy breaches as required in some jurisdictions (e.g., the data protection authorities) and depending on the level of risk;
- allowing an aggrieved PII principal access to appropriate and effective sanctions and/or remedies, such as rectification, expungement or restitution if a privacy breach has occurred; and
- considering procedures for compensation for situations in which it will be difficult or impossible to bring the natural person's privacy status back to a position as if nothing had occurred.

**10. Information security** Adhering to the information security principle means:

- protecting PII under its authority with appropriate controls at the operational, functional and strategic level to ensure the integrity, confidentiality and availability of the PII, and protect it against risks such as unauthorized access, destruction, use, modification, disclosure or loss throughout the whole of its life cycle;
- choosing PII processors that provide sufficient guarantees with regard to organizational, physical and technical controls for the processing of PII and ensuring compliance with these controls;
- basing these controls on applicable legal requirements, security standards, the results of systematic security risk assessments as described in ISO 31000, and the results of a cost/benefit analysis;
- implementing controls in proportion to the likelihood and severity of the potential consequences, the sensitivity of the PII, the number of PII principals that might be affected, and the context in which it is held;

- limiting access to PII to those individuals who require such access to perform their duties, and limit the access those individuals have to only that PII which they require access to in order to perform their duties;
- resolving risks and vulnerabilities that are discovered through privacy risk assessments and audit processes; and
- subjecting the controls to periodic review and reassessment in an ongoing security risk management process.

#### 11. Privacy compliance Adhering to the privacy compliance principle means:

- verifying and demonstrating that the processing meets data protection and privacy safeguarding requirements by periodically conducting audits using internal auditors or trusted third-party auditors;
- having appropriate internal controls and independent supervision mechanisms in place that assure compliance with relevant privacy law and with their security, data protection and privacy policies and procedures; and
- developing and maintaining privacy risk assessments in order to evaluate whether program and service delivery initiatives involving PII processing comply with data protection and privacy requirements.

*C.1.4 Privacy by Design Principles for Big Data by Ann Cavoukian and Jeff Jonas (2010).* Cavoukian and Jonas has extended the Cavoukian's privacy principle [10] as follows [11] :

**01. Full Attribution** Every observation (record) needs to know from where it came and when. There cannot be merge/purge data survivorship processing whereby some observations or fields are discarded.

**02. Data Tethering** Adds, changes and deletes occurring in systems of record must be accounted for, in real time, in sub-seconds.

**03. Analytics on Anonymised Data** The ability to perform advanced analytics (including some fuzzy matching) over cryptographically altered data means organizations can anonymise more data before information sharing.

**04. Tamper-Resistant Audit Logs** Every user search should be logged in a tamper-resistant manner-even the database administrator should not be able to alter the evidence contained in this audit log.

**05. False Negative Favouring Methods** The capability to more strongly favour false negatives is of critical importance in systems that could be used to affect someone's civil liberties.

**06. Self-Correcting False Positives** With every new data point presented, prior assertions are re-evaluated to ensure they are still correct, and if no longer correct, these earlier assertions can often be repaired in real time.

**07. Information Transfer Accounting** Every secondary transfer of data, whether to human eyeball or a tertiary system, can be recorded to allow stakeholders (e.g., data custodians or the consumers themselves) to understand how their data is flowing.

*C.1.5 Wright and Raab Privacy Principles.* [60] :

**01. Right to dignity**, i.e., freedom from infringements upon the person or his / her reputation.

**02. Right to be let alone** (privacy of the home, etc.).

**03. Right to anonymity**, including the right to express one's views anonymously.

**04. Right to autonomy**, to freedom of thought and action, without being surveilled.

**05. Right to individuality and uniqueness of identity.**

**06. Right to assemble or associate with others without being surveilled.**

**07. Right to confidentiality and secrecy of communications.**

**08. Right to travel** (in physical or cyber space) without being tracked.

**09. People should not have to pay in order to exercise their rights of privacy** (subject to any justifiable exceptions), nor be denied goods or services or offered them on a less preferential basis.

*C.1.6 Fisk et al. (2015) Principles.* [14] :

**01. Principle of Least Disclosure** Systems should strive to disclose as little to others as possible, while still sharing.

**02. Principle of Qualitative Evaluation** One must balance (subjectively) costs and benefits for privacy and progress.

**03. Principle of Forward Progress** Organizations must not become paralyzed by Least Disclosure and Qualitative Evaluation.

## C.2 Privacy Strategies

*C.2.1 Privacy Strategies by Rost and Bock (2011).* Rost and Bock (2011) has suggested six privacy strategies [53].

01. Availability

02. Integrity

03. Confidentiality

04. Transparency

05. Unlinkability

06. Ability to intervene

*C.2.2 Privacy Strategies by Hoepman.* Hoepman (2014) has proposed eight privacy design strategies [19].

**01. Minimise** The most basic privacy design strategy is MINIMISE, which states that the amount of personal data that is processed should be restricted to the minimal amount possible.

**02. Hide** Any personal data, and their interrelationships, should be hidden from plain view.

**03. Separate** Personal data should be processed in a distributed fashion, in separate compartments whenever possible.

**04. Aggregate** Personal data should be processed at the highest level of aggregation and with the least possible detail in which it is (still) useful.

**05. Inform** Data subjects should be adequately informed whenever personal data is processed.

**05. Inform** Data subjects should be adequately informed whenever personal data is processed.

**06. Control** Data subjects should be provided agency over the processing of their personal data.

**07. Enforce** A privacy policy compatible with legal requirements should be in place and should be enforced.

**08. Demonstrate** Be able to demonstrate compliance with the privacy policy and any applicable legal requirements

### C.3 Privacy Guidelines

#### C.3.1 *Privacy Guidelines by O'Leary (1995)*. [13]:

**01. Collection limitation** Data should be obtained lawfully and fairly, while some very sensitive data should not be held at all.

**02. Data quality** Data should be relevant to the stated purposes, accurate, complete and up-to-date: proper precautions should be taken to ensure this accuracy.

**03. Purpose specification** The purposes for which data will be used should be identified, and the data should be destroyed if it no longer serves the given purpose.

**04. Use limitation** Use of data for purposes other than specified is forbidden, except with the consent of the data subject or by authority of the law.

**05. Security safeguards** Agencies should establish procedures to guard against loss, corruption, destruction, or misuse of data.

**06. Openness** It must be possible to acquire information about the collection, storage, and use of personal data.

**07. Individual participation** The data subject has a right to access and challenge the data related to him or her.

**08. Accountability** A data controller should be accountable for complying with measures giving effect to all these principles.

#### C.3.2 *Privacy Guidelines by Perera et al. (2019)*. [44]:

**01. Minimise data acquisition** This guideline suggests to minimise the amount of data collected or requested by an IoT platform or application. Minimisation includes:

- Minimising data types (e.g., energy consumption, water consumption, temperature)
- Minimum duration (e.g., hours, days, weeks, months)
- Minimum frequency (e.g., sampling rate: one second, 30 seconds, minutes)
- Minimum amount of data (e.g., kilobytes, megabytes, gigabytes)

**02. Minimise number of data sources** This guideline suggests to minimise the number of data sources used by an IoT platform or application. Depending on the task at hand, it may be required to collect data from different sources. Multiple data sources may hold pieces of information about an individual (e.g., An activity tracking service may hold an individual's activity data while a hospital may hold his health records). Aggregation of data from multiple sources allow malicious parties to identify sensitive personal information of an individual that that could lead to privacy violations.

**03. Minimise raw data intake** Whenever possible, IoT applications should reduce the amount of raw data intake. Raw data could lead to secondary usage and privacy violation. Therefore, IoT platforms should consider converting (or transforming) raw data into secondary context data. For example, IoT applications can extract orientation (e.g. sitting, standing, walking) by processing accelerometer data and store only the results (i.e. secondary context) and delete the raw accelerometer data.

**04. Minimise knowledge discovery** This guideline suggests to minimise the amount of knowledge discovered within an IoT application. IoT applications should only discover the knowledge necessary to achieve their primary objectives. For example, if the objective is to recommend food plans, it should not attempt to infer users' health status without their explicit permission.

**05. Minimise data storage** This guideline suggests to minimise the amount of data (i.e. primary or secondary) stored by an IoT application. Any piece of data that is not required to perform a certain task should be deleted. For example, raw data can be deleted once secondary contexts are derived. Further, personally identifiable data may be deleted without storing.

**06. Minimise data retention period** This guideline suggests to minimise the duration for which data is stored (i.e. avoid retaining data for longer than needed). Long retention periods provide more time for malicious parties to attempt accessing the data in unauthorized manner. Privacy risks are also increased because long retention periods could lead to unconsented secondary usage.

**07. Hidden data routing** In IoT, data is generated within sensing devices. The data analysis typically happens within cloud servers. Therefore, data is expected to travel between different types of computational nodes before arriving at the processing cloud servers. This type of routing could reveal user locations and usage from anyone conducting network surveillance or traffic analysis. To make it more difficult for Internet activities to be traced back to the users, this guideline suggests that IoT applications should support and employ anonymous routing mechanism (e.g., torproject.org).

**08. Data anonymisation** This guideline suggests to remove personally identifiable information before the data gets used by IoT applications so that the people described by the data remain anonymous. Removal of personally identifiable information reduces the risk of unintended disclosure and privacy violations.

**09. Encrypted data communication** This guideline suggests that different components in an IoT application should consider encrypted data communication wherever possible. Encrypted data communication would reduce the potential privacy risks due to unauthorised access during data transfer between components. There are multiple data communication approaches based on the components involved in an IoT application, namely, 1) device-to-device, 2) device- to-gateway, 3) device-to-cloud, and 4)gateway-to-cloud. Sensor data communication can be encrypted using symmetric encryption AES 256 in the application layer. Typically, device- to-device communications are encrypted at the link layer using special electronic hardware included in the radio modules. Gateway-to-cloud communication is typically secured through HTTPS using Secure Sockets Layer (SSL) or Transport Layer Security (TLS).

**10. Encrypted data processing** This guideline suggests to process data while encrypted. Encryption is the process of encoding data in such a way that only authorised parties can read it. However, sometimes, the party who is responsible for processing data should not be allowed to read data. In such circumstances, it is important to process data while they are in encrypted form. For example, homomorphic encryption is a form of encryption that allows computations to be carried out on cipher-text, thus generating an encrypted result which, when decrypted, matches the result of operations performed on the plain-text.

**11. Encrypted data storage** This guideline suggests that IoT applications should store data in encrypted form. Encrypted data storage reduces any privacy violations due to malicious attacks and unauthorised access. Data encryption can be applied in different levels from sensors to the cloud. Depending on the circumstances, data can be encrypted using both hardware and software technologies.

**12. Reduce data granularity** The granularity is the level of depth represented by the data. High granularity refers to atomic grade of detail and low granularity zooms out into a summary view of data. For example, dissemination of location can be considered as coarse- grained and full address can be considered as fine-grained. Therefore, releasing fine grained information always has more privacy risks than coarse-grained data as they contain more information. Data granularity has a direct impact on the quality of the data as well as the accuracy of the results produced by processing such data. IoT applications should request the minimum level of granularity that is required to perform their primary tasks. Higher level of granularity could lead to secondary data usage and eventually privacy violations.

**13. Query answering** This guideline suggests to release high-level answers to the query when dissemination without releasing raw data. For example, a sample query would be 'how energy efficient a particular household is?' where the answer would be in 0-5 scale. Raw data can always lead to privacy violations due to secondary usage. One such implementation is openPDS/SafeAnswers where it allows users to collect, store, and give high level answers to the queries while protecting their privacy.

**15. Distributed data processing** This guideline suggests that an IoT application should process data in a distributed manner. Similar, approaches are widely used in traditional wireless sensor network domain. Distributed processing avoids centralised large-scale data gathering. As a result, it deters any unauthorised data access attempts.

**16. Distributed data storage** This guideline recommends storing data in a distributed manner. Distributed data storage reduces any privacy violation due to malicious attacks and unauthorised access. It also reduces privacy risks due to unconsented secondary knowledge discovery.

**17. Knowledge discovery based aggregation** Aggregation of information over groups of attributes or groups of individuals, restricts the amount of detail in the personal data that remains. This guideline suggests to discover knowledge through aggregation and replace raw data with discovered new knowledge. For example, 'majority of people who visited the park on [particular date] were young students' is an aggregated result that is sufficient (once collected over a time period) to perform further time series based sales performance analysis of a near-by shop. Exact timings of the crowd movements are not necessary to achieve this objective.

**18. Geography based aggregation** This guideline recommends to aggregate data using geographical boundaries. For example, a query would be 'how many electric vehicles used in each city in UK'. The results to this query would be an aggregated number unique to the each city. It is not required to collect or store detailed about individual electric vehicle.

**19. Chain aggregation** This guideline suggests to perform aggregation on-the-go while moving data from one node to another. For example, if the query requires a count or average, it can be done without pulling all the data items to a centralised location. Data will be sent from one node to another until all the nodes get a chance to respond. Similar techniques are successfully used in wireless sensor networks. This type of technique reduces the amount of data gathered

by a centralised node (e.g. cloud server). Further, such aggregation also eliminates raw data from the results by reducing the risk of secondary data usage.

**20. Time-Period based aggregation** This guideline suggests to aggregate data over time (e.g. days, week, months). Aggregation reduces the granularity of data and also reduces the secondary usage that could lead to privacy violations. For example, energy consumption of a given house can be acquired and represented in aggregated form as 160 kWh per month instead of gathering energy consumption on daily or hourly basis.

**21. Category based aggregation** Categorisation based aggregation approaches can be used to reduce the granularity of the raw data. For example, instead of using exact value (e.g. 160 kWh per month), energy consumption of a given house can be represented as 150-200 kWh per month. Time-Period based and category based aggregation can be combined together to reduce data granularity.

**22. Information Disclosure** This guideline suggests that data subjects should be adequately informed whenever data they own is acquired, processed, and disseminated. Inform can take place at any stage of the data life cycle. Further, inform can be broadly divided into two categories: pre-inform and post-inform. Pre-inform takes place before data enters to a given data life cycle phase. Post-inform takes place soon after data leaves a given data life cycle phase.

- Consent and Data Acquisition: what is the purpose of the data acquisition?, What types of data are requested?, What is the level of granularity?, What are the rights of the data subjects?
- Data Pre-Processing: what data will be taken into the platform?, what data will be thrown out?, what kind of pre-processing technique will be employed?, what are the purposes of pre-processing data?, what techniques will be used to protect user privacy?
- Data Processing and Analysis: what type of data will be analysed?, what knowledge will be discovered?, what techniques will be used?
- Data Storage: what data items will be stored? how long they will be stored? what technologies are used to store data (e.g. encryption techniques)? is it centralised or distributed storage? will there be any back up processes?
- Data Dissemination: with whom the data will be shared? what rights will receivers have? what rights will data subjects have?

**23. Control** This guideline recommends providing privacy control mechanisms for data subjects. Control mechanisms will allow data owners to manage data based on their preference. There are different aspects that the data owner may like to control. However, controlling is a time consuming task and not every data owner will have the expertise to make such decisions. Therefore, it is a software architect's responsibility to carefully go through the following list of possibilities and determine what kind of controls are useful and relevant to data owners in a given IoT application context. Further, it is important to provide some kind of default set of options for data owners to choose from, specially in the cases where data subjects do not have sufficient knowledge. Some potential aspects that a data owner may like to control are 1) data granularity, 2) anonymisation technique, 3) data retention period, 4) data dissemination.

**24. Logging** This guideline suggests to log events during all phases. It allows both internal and external parties to examine what has happened in the past to make sure a given system has performed as promised. Logging could include but not limited to event traces, performance parameters, timestamps, sequences of operations performed over data, any human interventions. For example, a log may include the timestamps of data arrival, operations performed in order to anonymise data, aggregation techniques performed, and so on.

**25. Auditing** This guideline suggests to perform systematic and independent examinations of logs, procedures, processes, hardware and software specifications, and so on. The logs above could play a significant role in this processes. Non-disclosure agreements may be helpful to allow auditing some parts of the classified data analytics processes.

**26. Open Source** Making source code of an IoT application open allows any external party to review code. Such reviews can be used as a form of compliance demonstration. This allows external parties to examine the code bases to verify and determine whether a given application or platform has taken all measures to protect user privacy.

**27. Data Flow** Data flow diagrams (e.g. Data Flow Diagrams used by Unified Modelling Language) allow interested parties to understand how data flows within a given IoT application and how data is being treated. Therefore, DFDs can be used as a form of a compliance demonstration.

**28. Certification** In this context, certification refers to the confirmation of certain characteristics of an system and process. Typically, certifications are given by a neutral authority. Certification will add trustworthiness to IoT applications. TRUSTe (truste.com) Privacy Seal is one example, even though none of the existing certifications are explicitly designed to certify IoT applications.

**29. Standardisation** This guideline suggests to follow standard practices as a way to demonstrate privacy protection capabilities. Industry wide standards (e.g. AllJoyn allseenalliance.org) typically inherit security measures that would reduce some privacy risks as well. This refers to the process of implementing and developing technical standards. Standardisation can help to maximise compatibility, interoperability, safety, repeatability, or quality. Standardisation will help external parties to easily understand the inner workings of a given IoT application.

**30. Compliance** Based on the country and region, there are number of policies, laws and regulations that need to be adhered to. It is important for IoT applications to respect guidelines. Some regulatory efforts are ISO 29100 Privacy framework, OECD privacy principles, and European Commission Protection of personal data.

#### C.4 Privacy Patterns

This section presents the existing privacy patterns which are gathered from [47, 48].

1. Protection against Tracking
2. Location Granularity
3. Minimal Information Asymmetry
4. Informed Secure Passwords
5. Awareness Feed
6. Encryption with user-managed keys
7. Federated Privacy Impact Assessment
8. Use of dummies
9. Who's Listening
10. Privacy Policy Display
11. Layered Policy Design
12. Discouraging blanket strategies
13. Reciprocity
14. Asynchronous notice
15. Abridged Terms and Conditions
16. Policy Matching Display
17. Incentivized Participation
18. Outsourcing [with consent]
19. Ambient Notice
20. Dynamic Privacy Policy Display
21. Privacy Labels
22. Data Breach Notification Pattern
23. Pseudonymous Messaging
24. Onion Routing
25. Strip Invisible Metadata
26. Pseudonymous Identity
27. Personal Data Store
28. Trust Evaluation of Services Sides
29. Aggregation Gateway
30. Privacy icons
31. Privacy-Aware Network Client
32. Sign an Agreement to Solve Lack of Trust on the Use of Private Data Context
33. Single Point of Contact
34. Informed Implicit Consent
35. Enable/Disable Functions
36. Privacy Colour Coding
37. Appropriate Privacy Icons
38. User data confinement pattern
39. Icons for Privacy Policies
40. Obtaining Explicit Consent
41. Privacy Mirrors
42. Appropriate Privacy Feedback
43. Impactful Information and Feedback
44. Decoupling [content] and location information visibility
45. Platform for Privacy Preferences
46. Access control
47. Pay Back
48. Privacy dashboard
49. Preventing mistakes or reducing their impact
50. Obligation Management
51. Informed Credential Selection

52. Anonymous Reputation-based Blacklisting
53. Negotiation of Privacy Policy
54. Reasonable Level of Control
55. Masquerade
56. Buddy List
57. Privacy Awareness Panel
58. Lawful Consent
59. Privacy Aware Wording
60. Sticky Policies
61. Personal Data Table
62. Informed Consent for Web-based Transactions
63. Added-noise measurement Obfuscation
64. Increasing awareness of information aggregation
65. Attribute Based Credentials
66. Trustworthy Privacy Plug-in
67. [Support] Selective Disclosure
68. Private link
69. Anonymity Set
70. Active broadcast of presence
71. Unusual Activities
72. Identity Federation Do Not Track Pattern
73. Dynamic Location Granularity