Going underground: an exploration of the interfaces between underground urban transport infrastructure and its environment

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Abstract

With the continued urbanization and densification of cities worldwide the planning, and use of urban underground space (UUS) is of clear interest to urban and transport planners;

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and asset owners/managers. Effective strategies for the management of UUS and its environment once built are required and critical insight of how current use of these spaces affect and are affected by each other, enables effective planning and asset management strategies to be developed now and for the future.

This paper argues that the management of existing and development of new urban infrastructure and its interfaces with UUS requires consideration of what is/will be there; who does/will own it; and how it must/will be protected. However, there appears to be a gap in the literature relating to how and why these interfaces occur and how they could and should be managed effectively.

Taking the case of existing urban underground metro infrastructure, this paper demonstrates how understanding the *presence*, *property*, and *protection* interfaces of urban underground infrastructure and its environment at different levels of consideration is essential to urban and transport planning and management.

The paper concludes with a challenge to current strategies and proposals for the development and management of UUS and its environment, questioning whether they are fit for current and future demands and changes.

Highlights

- Urban underground metros have direct and indirect interfaces with their environment
- Urban underground metros influence the design of their urban environment
- The environment of urban underground metros influences their safe presence and operation
- Comprehension of presence; property; protection, are essential to urban management

Keywords: urban; underground; space; metro; railway; infrastructure

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1.0 Introduction

Urban underground space (UUS) does not occur or exist by itself. It generally requires physical structures, referred to as urban underground infrastructure (UUI), to create that space (e.g. tunnels; floors; ceilings; girders; walls; shafts). These structures interact with the subsoil and other urban infrastructure (buildings; basement levels; other tunnels; transport infrastructure; utilities). Typically, the structures and land can be owned by or be the responsibility of different parties, at different interfaces, within the same footprint, or extend beyond these. For example, the Toronto pedestrian subway system is a network of subways (UUS formed from UUI) owned privately, but used by the general public. They are located under private buildings and property, and extend under the public highway. They also connect with other privately owned subways and buildings (City of Toronto, 2018). Therefore interfaces occur at different locations below as well as above ground. The continued safe presence and operation of both UUI and its environment is dependent on effective asset management. This involves strategies and actions to ensure inspection, maintenance, repair and replacement of assets. It also includes consideration and mitigation of risk through change, which may occur over the whole lifetime of assets. Past changes have direct and indirect effects on the UUI or its environment for the future and thus must also be considered. Having an effective means of determining the interfaces between urban infrastructure and how change has occurred, is an important part of ensuring the safe continuing presence and operation of existing infrastructure as well as for planning future infrastructure.

Effective asset management strategies must ensure that each interfacing party (property owner/maintainer) has a clear understanding of the primary interfaces involved in the operation and management of UUI. Darroch et al, 2016 proposed a conceptual framework (fig 1) which described these in basic terms as: what is there (*presence*); who owns it (*property*); how is it protected (*protection*). It is recommended that these be clarified, agreed, and documented between all interested parties, for the whole lifetime of the assets, and beyond their removal/change.

Ongoing research into the application of a conceptual framework to identify and clarify the interfaces between UUI and its environment, reported in this paper, has determined that the level of analysis required by the different stakeholders within an urban environment should also be considered. These stakeholders are likely to include: urban/transport planners; utilities/land owners; transport companies/authorities. The different levels of analysis proposed are: holistic (overall area); macro (general interfaces within a specific location); and micro (specific detail of how and why those interfaces occur within a specific site).

From reviews of current literature, it appears that there are few co-ordinated considerations of the three primary interfaces of *presence, property, and protection* for UUI. There are papers which discuss, propose, and promote development of UUI and policy changes to effect this generally (*presence*) (Hunt, et al., 2016; Admiraal and Cornaro, 2016). Others consider division of land and subsoil to enable development (*property*) (International Tunnelling Association, 1991; Groetelaers and Ploeger, 2007). Some professional publications also demonstrate the need to protect UUI (*protection*) (Perry, 2014; Viggiani, and de Sanctis 2009). But none to date give holistic, macro, or micro examples or case studies of how UUS interfaces with its environment collectively (*presence, property,* **and** *protection*). This is a concern given both the short and long term impacts uncoordinated proposals for urban and transport construction will have on cities now and in to the future.

Through the practical application of the conceptual framework introduced in Darroch et al. 2016, this paper argues that appreciation, understanding and knowledge of how assets and their environment interact is of direct relevance to research and practice in urban and transport: planning; development; and management (Gov.uk, 2017 GLA, 2018; WSP, 2017(a); WSP, 2017(b); Ashurst, 2017). Additionally, it is suggested that UUI interfaces should be planned, designed, constructed, and managed for their whole life cycle, with the factors of presence, property, and protection clearly documented.

Using examples from existing urban underground metro infrastructure (UUMI), this paper demonstrates how understanding the *presence, property*, and *protection* interfaces of urban underground infrastructure and its environment at different levels of analysis is essential to urban and transport planning and management. The paper is structured as follows:

- Section 2 discusses levels of applicability and analyses applied to the Darroch et al, 2016 conceptual framework;
- It also considers the high level questions to be asked when applying the conceptual framework to any one or group of assets within a specific or general environment;
- Section 3 presents examples from the London Underground (LU) network of physical, property, and presence;
- Section 4 contains a simple case study applying the conceptual framework to an example location on the LU network;

- Section 5 presents two suggested transferability scenarios to further demonstrate the characteristics of the three primary interfaces of *presence, property,* and *protection*.

The paper concludes with a challenge to current approaches towards the development and management of urban underground space, and its environment. The principles proposed in this paper are offered as a means to identify and clarify how existing and proposed urban underground space interfaces with its environment, something which appears to be currently lacking in both the literature and professional practice.

1.2 Explanation of key terms

A number of key terms are used within this paper and are defined as follows:

- Urban environment – densely developed area containing residential, commercial, industrial, retail buildings; utilities; and transport infrastructure.
- Urban underground space (UUS) - the space created within the sub-soil of the city not necessarily formed of tunnels or fully underground spaces, but below ground level. It may be enclosed (tunnels etc.) or open to the atmosphere, either at ground level or above (open voids (cuttings); ventilation shafts etc.).
- Air space – the actual UUS created within enclosed or open urban underground infrastructure (UUI); the space above buildings, highways, or railway; it can be above or below ground level (where there is no covering over; e.g. an open cutting).
- Urban underground infrastructure (UUI) - the engineered structures that enable UUS to exist. These can be tunnels, sewers, shafts, passages, retaining walls, girders and rafts.
- Sub-surface – the term used here as between 0.2 and 5m to the top of the structure forming the UUI (tunnel/covered way). For example, a sub-surface tunnel (0.2-5m deep), other than a deep tube tunnel (2-33m deep).
- Sub-surface railway - those railways built between 1860 and 1884 within the Transport for London (TfL) fare zone 1, which are commonly and incorrectly perceived to have been constructed wholly under road and by cut and cover methods.
- Sub-soil – the ground within which the UUI is created to form the actual space. For example, a tunnel is formed by excavating the ‘sub-soil’. Sub-soil can also mean the surrounding ground around that UUI.

- Tube railways – those railways constructed from the mid-1880s onwards using a Greathead tunnelling shield or some technological development enabling the sub-soil to be excavated at depths up to 35m underground without substantial disruption to the surface above.
- Urban underground metro infrastructure (UUMI) – the collective term for all UUS/UUI assets and air space within them relating to an underground metro system within an urban area, whether sub-surface or tube. This includes but is not limited to: tunnels; shafts; station buildings; entrances to stations; retaining walls etc.
- General Legislation – legislation that is incorporated within authorising legislation, and provides specific requirements which must be accommodated unless a variation is made within the authorising legislation.
- Authorising Legislation – the Act of Parliament specifically relating to the construction of/land acquisition for/extension of time for/changes to the construction and presence of railway infrastructure.

2.0 Background to the research

Darroch et al., 2016, introduced a conceptual framework that was developed to highlight and advance understanding of the complex relationship between UUMI and its environment (fig.1). It was initially developed through the practical and academic knowledge and experience of the lead researcher on the legal and historical aspects of LU. This earlier research also built on initial considerations of the relationship between UUMI and its urban environment in London within Darroch, 2012 and 2014. While the development of the conceptual framework was particularly focused on London, it was tested on the Glasgow Subway, in Scotland, for transferability within a UK context (Darroch et al, 2016).

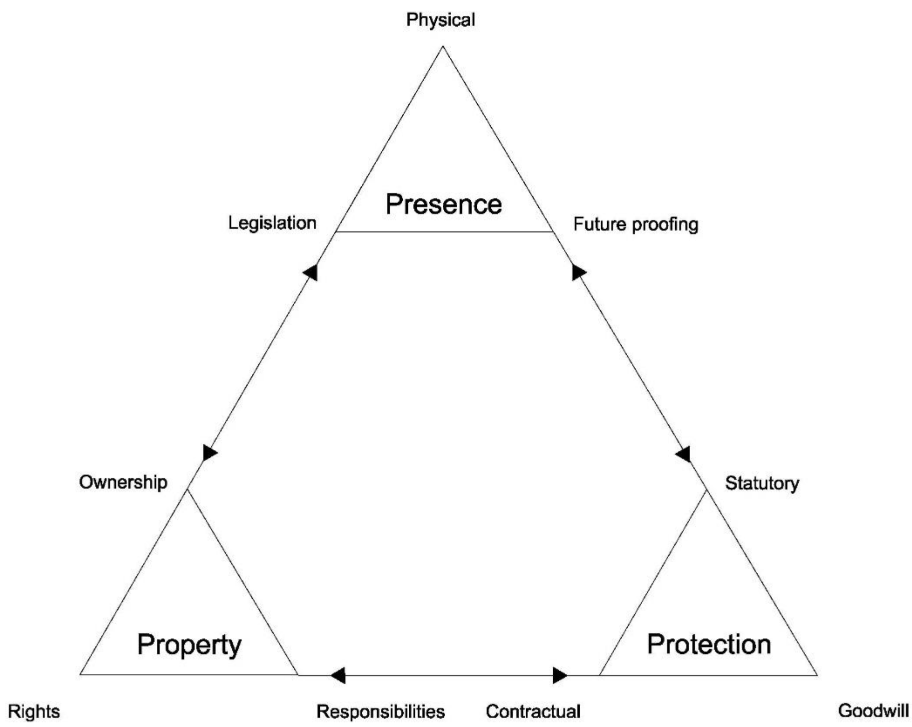

Fig.1: *The conceptual framework developed to assist understanding of the complex relationship between urban underground metro infrastructure (UUMI) and its environment.*

Source*: based on Darroch et al., 2016.*

The next stage of the research, and the focus of this paper, was the practical application of the conceptual framework to specific sample scenarios on the LU network. The term "*scenario*" is used here to mean '*a setting*', or an instance of an event in outline, as a distinctly different consideration than a detailed case study. Investigation commenced with an overview analysis of what was *present*. More detailed analysis of selected samples, chosen for their reflection of common occurrences or their own peculiarities, was then undertaken. These included but were not limited to: UUMI under highway; UUMI under building; UUMI within a building. This was to determine and document textually, in tables, and diagrams the nature and variety of these interfaces from the presence, property, and protection perspectives. From these it was possible to determine the typicality of occurrences of presence, property, and protection, and how and why changes in these primary interfaces occur. Fig.2 shows a building erected over a former open section of railway. The building is directly adjacent to an entrance into St James's Park LU station, on Palmer Street. The railway retaining walls (UUMI) are located under the buildings either side, perpendicular to the road. This is one outline *scenario* of many such scenarios across the LU network (Dennis, 2013; WSP, 2018).

Fig.2: *A single storey building erected over a former open section of sub-surface railway, in Palmer Street, Westminster, London. Such a scenario as this can be representative of other locations on a metro system or other systems.* ***Source:*** *Nathan Darroch.*

2.1 Levels of applicability and analysis

From the sample scenario research it was identified that when considering UUMI and its interfaces with its environment, it is important to approach it with a range of understanding (Bobylev, 2016), defined here as: *Holistic*; *Macro*; and *Micro*. These are outlined in Table 1 and represented within fig.3. As can be seen from Table 1, different stakeholders (planners; owners; maintainers; developers; contractors; asset managers) with an interest in urban and transport assets will have various levels of detail requirements for the interfaces involved. Each will require some degree of appreciation, understanding, or knowledge of the three primary interfaces to ensure that they can undertake their role of urban and transport operation, design, and planning effectively. For example, can a property owner wishing to create a basement (a type of UUS) under their house do so effectively and safely without first knowing what is beneath their house? If there is a tunnel there (*presence*): what is the depth of subsoil owned by the house owner? (*property*); how could the proposed works affect the safe presence of the tunnel in the short and long term? (*protection*).

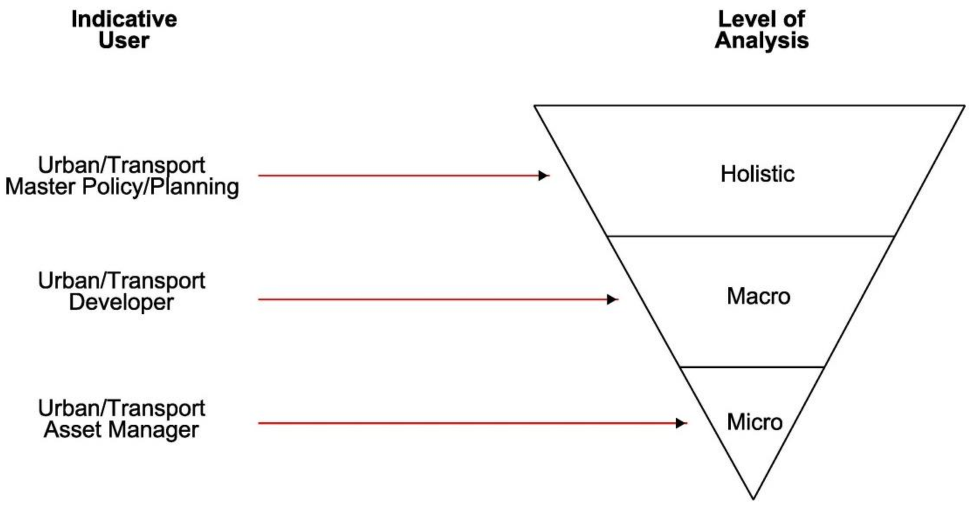

Fig.3: *Levels of analysis for three suggestive primary users of the conceptual framework. Each party would require a specific level of knowledge for their roles in urban asset management.*

A planning officer, advising on and processing a planning application for the basement installation, would ideally have an *appreciation* of the fact that there is a tunnel under the property. They then would understand why they have a statutory requirement to consult railway asset managers of planning applications within 10m of the railway (Darroch et al, 2016, 126; HMSO, 2015); and advise the planning applicant to contact the UUMI owner and to enter discussions with them (HMSO, 2015; Bobylev, 2009). Through these steps the applicant and the UUMI owner could complete a *macro* analysis of what is intended in principle; agree the proposals and designs; and ensure safe methods of working. Once both parties are agreed on the processes they would enter the construction stage with *micro* analysis further contributing to decision making, and actions (TfL, 2016). The *micro* knowledge therefore informs how asset risk will be mitigated (*protection*) in the short term of the works; and how the long-term presence of, or changes to, the existing, and additional assets, of both parties will be managed for their whole lifecycle (Crossrail, 2016; TfL, undated(a); MTR, 2014).

Level of analysis	**Definition**	**Description**

Holistic	Urban/Metro master planning stage - planning for change in the future and having an appreciation of what is present.	The larger environment under consideration, including: what is within it and where (*presence*); consultees - ownership of land or assets (*property*); what is required to ensure ongoing safe presence (*protection*). Generally, within an engineering zone of influence based on the proposed redevelopment/works/risk (TfL, 2017). (see fig.7).
Macro	The urban developer stage - demolition and reconstruction of existing buildings and understanding of the primary interfaces (fig.8)	The understanding of what is there (presence); who owns it (property), and how it is protected (protection). Considerations include who owns or is responsible for what assets; and what may happen if a change is planned or occurs within a specific area in relation to the collective UUI. Any metro or urban asset owner must have details of these interfaces to be able to design, plan, construct, and manage their assets for their whole lifecycle and to plan for changes to these (future proofing) (see fig.8).
Micro	The asset management stage – Specific knowledge of the presence, property and protection interfaces of specific assets.	Specific details of how assets within a defined site inter-relate from *presence, property,* and *protection* perspectives. What assets are there (*physical*), what allows them to be there (*legislation*), are there specific requirements/stipulations to ensure longevity (*future proofing*); who owns which asset (*ownership*), how are, or will, specific assets be managed for their whole life cycle, by whom, and why (*rights and responsibilities*); what is required to ensure they continue to function when change occurs: is it written in to law (*statutory*), is there a contract (*contractual*), is there any express method of protection (*goodwill*)? (see fig.9).

Table 1: *The three levels of analysis and application of the conceptual framework.*

Failure to have sufficient detail at each level of analysis poses serious risks to the safe presence and operation of UUI, as was demonstrated in 2013. On that occasion an auger penetrated a Network Rail deep tube tunnel (fig, 4). Through the subsequent investigation, the UK Railway Accident Investigation Branch '*determined that approximately half of the piles required for* [a] *new development would have intersected with the tunnel had they been constructed*' (*presence*) (fig. 5) (RAIB, 2014). The explanation for this incident, in relation to this paper, was that it occurred because of a lack of *holistic* and *macro* understanding of what UUI was present within the development area. In addition, Network Rail, the tunnel owner (*property*), '*did not have any pro-active arrangements to identify developments which could affect the railway*' (*protection*).

The sample scenarios analysed for this research were to determine: what LU UUMI is present; how it relates to its urban environment; if the three primary interfaces are in effect at all those sample locations; the benefits and limitations of the conceptual framework in identifying how, when, and why these primary interfaces came to be; and its applicability to a wide range of different, but potentially common scenarios. For the larger sample area, the TfL Fare Zone 1 (TfL, undated(b)) was chosen as the most likely potential comparable area to other cities globally. This is because that area contains the most common features of a densely developed city globally which may be summarised as: commercial, residential, governmental, and retail environments; multiple transport modes (public highway; metro and other railway systems); urban infrastructure (roads; utilities; railways; bridges; tunnels; etc.); buildings of various ages and sizes, ranging from single to 72 storeys above ground, basement levels from 1 to at least 8+ storeys deep; many and varied types of UUMI, UUS, and UUI at varying depths (GLA, 2018; Darroch, 2012 and 2014).

While the Glasgow pilot study (Darroch et al, 2016) looked *holistically* at how the interfaces affect and are affected by their environment, the subsequent sample scenarios of the LU network considered the interfaces at *holistic* and *macro* levels. *Micro* analyses were identified as being too detailed and time consuming for the purposes of sampling.

Fig.4: *showing the auger on the track in the tunnel post-penetration. The service was suspended, and this train and its crew were sent to inspect the line after reports of water and debris pouring in to the tunnel by a passing passenger train.* ***Source:*** *RAIB, 2014.*

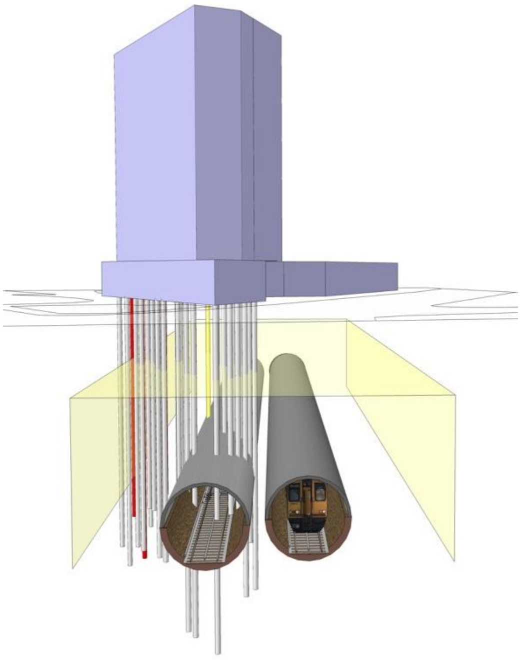

Fig.5: *showing the foundation design for a new development above the Network Rail tube railway, where an auger for the construction of the piled foundations penetrated the operational railway tunnel, used here as an example of UUI.* ***Source:*** *RAIB, 2014.*

3.0 The research methodology

Darroch et al, 2016, described the conceptual framework as a tool to assist identification of the primary and sub-interfaces between UUMI and its environment. Subsequently, its benefit as a tool to determine identification **and** clarification of interfaces has been developed and tested in practice through its application to the sample scenarios at macro level. However, for it to be a useful tool it was recognised that the upper triangle '*presence*' must have the '*physical*' sub-interface at the top, as represented in fig.1 above. The conceptual framework used as a tool requires the user to start from the top of the triangle and determine each sub-interface/enabler within each interface before moving on to the next interface. For example, for the presence interface: what is there *physically*; what allows it to be there (*legislation*); is it *future proofed*, and if so how (through legislation or contract)? Without identifying what is actually present, it can be difficult to determine what is owned, and what needs to be protected (Chrimes, 2006; Darroch, 2012; 2014; Darroch et al, 2016).

In addition, it was clearly identified that any *holistic, macro, or micro* sample scenario analyses must be from a qualitative approach, rather than quantitative. Urban and transport asset managers need to understand how UUI interfaces with its environment; how or why ownership and responsibilities for interfacing assets may be different within the same location; and how those assets must be protected. Therefore, understanding of the three primary interfaces and what enables them must be appropriate for an asset management practitioner's method of understanding, as exampled in the RAIB incident in 2013, above. Fig.6 shows a diagrammatic representation of the research processes and outcomes.

To enable this understanding therefore, the use of the conceptual framework as a tool was undertaken by asking the questions: what is present? (*presence*); who owns it? (*property*); how is it protected? (*protection*), for each sample scenario within TfL fare zone 1 at *holistic* and *macro* levels. For more detailed *micro* analyses the sub-interfaces can be used to identify relevant sources of data to build a greater more detailed knowledge. For example, what legislation enables the presence of UUMI within a specific scenario and what does it say about future proofing, property, and protection matters? In addition, it could be compared and contrasted with a later legal agreement which grants different rights over

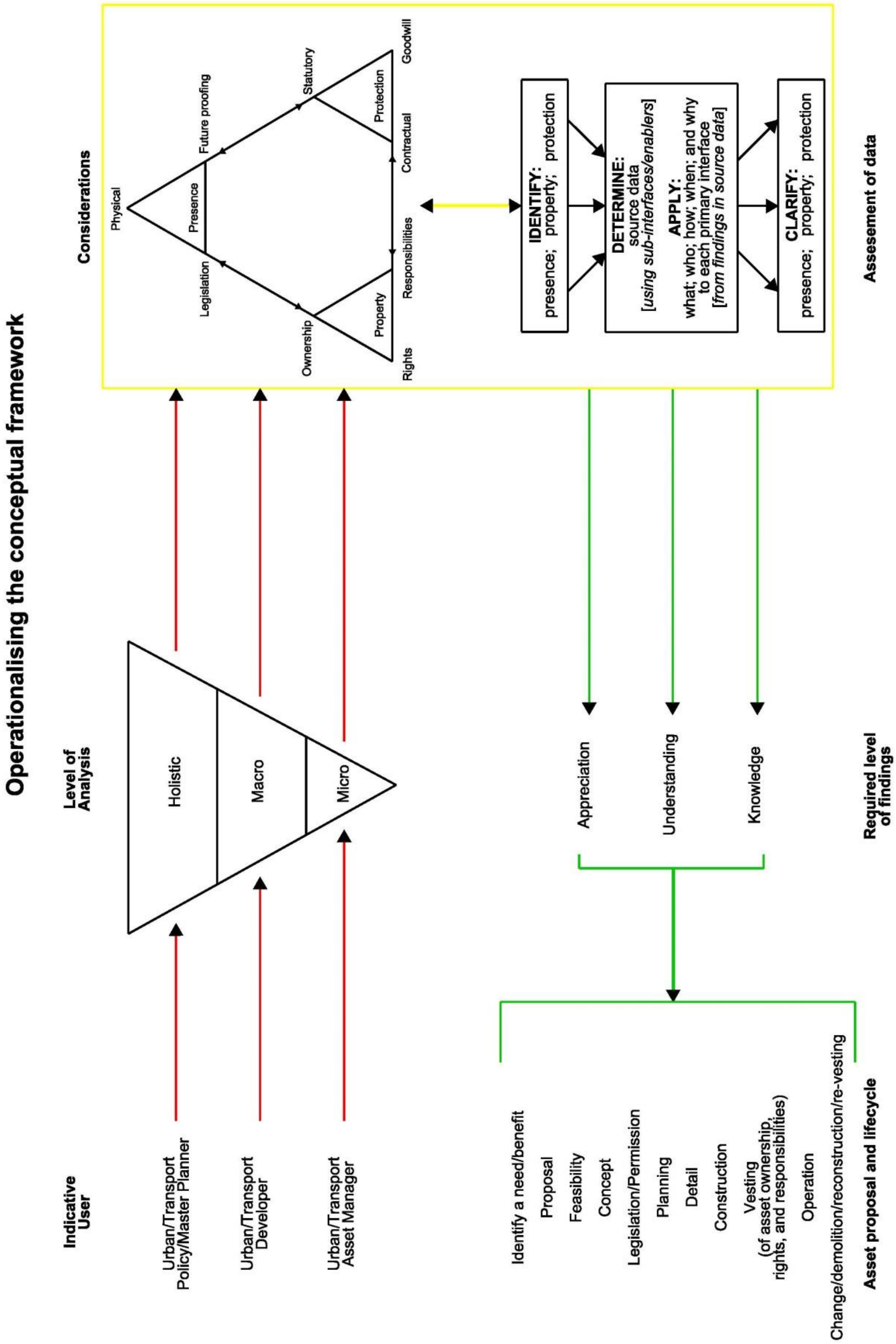

Fig.6: Diagram showing the process of analysis and application of the conceptual framework.

property to further clarify rights and responsibilities. This is demonstrated below, in the example case study (Section 4).

3.1 Holistic analyses

The *holistic* review of the sample scenarios focused wholly on the '*physical - presence*' of LU UUMI and its environment within the larger sample area. To enable *holistic* identification of '*physical – presence*' a Geographic Information System (GIS)[2] was used. This enabled digital sources such as current and historic Ordnance Survey (OS) mapping and LU survey data to be viewed in relation to one another (as shown in fig.7). The LU survey data showed UUMI location and its nature (type of tunnel; open cutting etc.)). In fig.7 grey shaded areas with dashed lines either side represent the Metropolitan Line and its station; other shaded un-outlined areas represent other UUS, such as: station ticket halls, platform tunnels, and connecting passages; dashed coloured lines represent the tunnel crown (uppermost point) of the different tube 'lines'. These UUMI can be between 0.2 and 30m below ground level (LU, 2009). Using this combination of mapping and survey data not only enabled identification of where UUMI is in relation to its environment, but also where it is formed of different structures. For example, girders rather than a brick '*tunnel*' (Baker, 1883, 17-18). The use of historic sources such as written materials and mapping enabled determination of how the UUMI and its environment may have changed over time. This was found to be a crucial factor in determining *macro* and *micro* considerations of the property, and protection interfaces. A 'live' site visit, or satellite imagery does potentially not enable this same appreciation or understanding.

[2] The software package 'Geomedia' provided by Intergraph (2017).

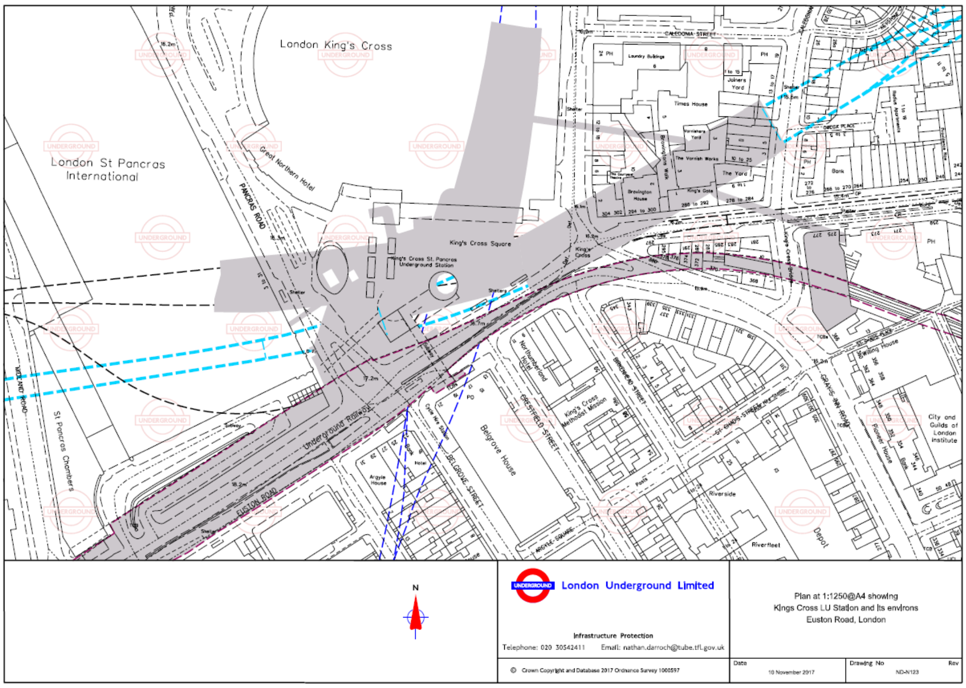

Fig.7: *1:2500 plan@A4 showing the London Underground Kings Cross station and its environs.* ***Source****: London Underground. Plan ©TfL; © Crown Copyright and database rights 2017 Ordnance Survey 1000035971.*

3.2 Macro analyses

The holistic analyses were undertaken to gain an appreciation of the primary interfaces and how they are influenced by and influence their environment through '*physical - presence*'. The macro analyses were undertaken to build on this appreciation, by identifying how and why the LU infrastructure interfaced with its environment. It is only with the *macro* and *micro* level analyses that any specific differences between *presence*, *property,* or *protection* interfaces may be clarified. For the *macro* sample scenarios therefore, other more specific sources of data were required. These included current and historic: OS mapping; LU survey data, as previously; further, more detailed LU survey data; reviews of academic, professional, and popular literature; legal documents, such as legislation, conveyances and leases; and engineering documents such as civil engineering drawings and inspection reports. Fig.8 shows an example of one such location considered as part of the *holistic and macro* review processes. In this instance a highway bridge, located over LU, and Network Rail, airspace, land, and infrastructure. Through the application of the conceptual framework, analysis of the primary interfaces of such locations as this was undertaken using the tools, methods and data outlined above. For example, '*property – ownership, rights, and responsibilities*' required the review of pertinent legal documents, such as those mentioned above. This more detailed review enabled an understanding of differences within the primary interfaces of similar scenarios. For example, despite being built and owned by the same company for nearly one hundred years, why is the UUMI now owned by different parties?

Fig.8: *Photograph, looking north, showing Ray Street highway bridge (centre distance); LU Metropolitan Line railway (to the right); and Network Rail Thameslink railway (to the left).*

Source: *Nathan Darroch.*

3.3 Micro analysis

Whilst *micro* analyses were not undertaken as part of the sampling research, it was identified as an essential part of understanding the interfaces between UUI and its environment. After all, it is *micro* analysis which enables detailed knowledge of the presence, property, and protection perspectives of individual assets within any one location. For example, fig.9 shows several girders above the LU Metropolitan line supporting buildings above. Using sources, identified through application of the conceptual framework and through further in-depth analyses and comparison of these, an asset manager could identify and clarify the primary interfaces. For example, taking *presence* for these structures alone – *micro* analysis would determine (fields within the conceptual framework are within brackets): what structures are present, their relative ages, and how they interact physically (*physical/ownership/protection*); what allows each parties' structure to be present (*legislation/property*); and how they are future proofed (*legislation/contractual/rights and responsibilities*), if at all. It is this knowledge therefore that enables effective short and long-term asset management of the girders; the buildings above; and the railway below.

To demonstrate the different levels of analysis suggested in Section 2, above, this section of the paper has discussed the findings from the application of the conceptual framework to sample scenarios across the LU network within TfL Fare Zone 1. However, for an effective demonstration of its applicability at *macro*, and an element of *micro* level analysis, the following section (4) presents a real life simplified case study.

Fig.9: *photograph showing girders supporting buildings, located above the Metropolitan line south of Farringdon station. Consider the primary interfaces, and how application of the conceptual framework can assist understanding of these.* ***Source:*** *London Underground.*

4.0 Application of the conceptual framework to a case study

So far, this paper has considered the application of the conceptual framework to three levels of analyses (*Holistic; Macro; and Micro*), to identify the three primary interfaces (*presence, property,* and *protection*), with some explanatory examples. To present the application of the conceptual framework in more detail an example is given here.

4.1 A building over the Metropolitan line north of Farringdon station

This *Macro* level case study considers number 54 Farringdon Road, a brick building erected above a brick railway tunnel, from the perspectives of the three primary interfaces.

Presence: Fig.10 shows its location (outlined blue) in relation to Ray Street Bridge in fig.8 above and outlined red in fig.10. Fig.11 shows a satellite image of the contextual area of the scenario. The Metropolitan line is located within an open cutting, below ground level. Fig.12 shows a photograph of the building, located over a brick tunnel, the railway here is also located above Network Rail railway, land, and airspace. The railway tunnel was constructed in the early 1860s as part of the Metropolitan Railway from Paddington to Farringdon, the world's oldest urban underground metro line, opened in 1863. The Network Rail Thameslink route, bottom right of image, passes below the Metropolitan line, and was constructed by the Metropolitan Railway in the mid-1860s and opened in 1867. The building was erected on top of the tunnel in the mid-1870s (British History Online, 2017). Public highways run either side of the railway cutting.

Property: Fig.13 shows the simplified property ownerships of the building and its adjacent/subjacent transport infrastructure. Both railways, and the building above, formerly belonged to the Metropolitan Railway from opening/construction until various dates. Sometime between the passing of the Metropolitan Railway Act 1883, and its sale in 1969, 54 Farringdon Road (Marked 'E') came under the management of the Metropolitan Surplus Lands Committee. This committee was a subsidiary of the Metropolitan Railway Company, formed under the powers within section 39 of the Metropolitan Railway Act 1885. Its purpose was to manage those surplus lands and buildings not required for the operation of the railway. Under section 98 of the London Passenger Transport Act 1933, the Metropolitan Surplus Lands Committee was excluded from the formation of the London Passenger Transport Board (predecessor to London Underground). Instead the Metropolitan Surplus Lands Company was formed, and all assets of the former Committee were re-vested (ownership, rights, and responsibilities) in to it (Statutory Declaration, 1938). The building

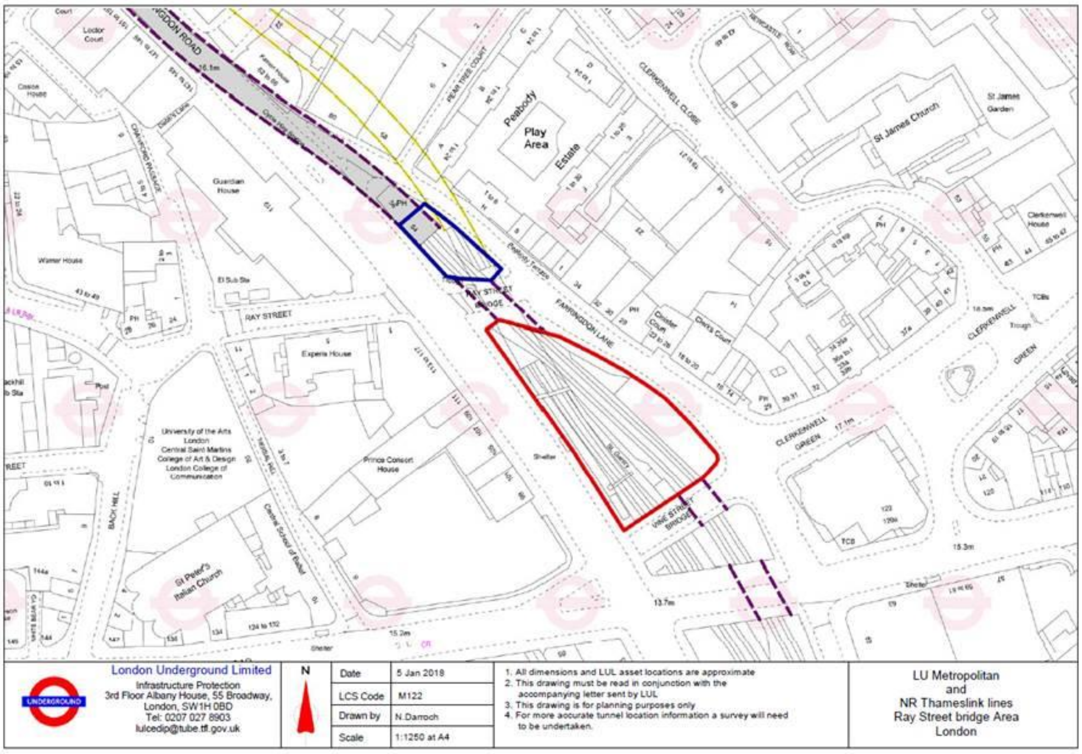

Fig.10: 1:1250@A4 plan showing the holistic environment of UUMI north of Farringdon LU station, in London. Note the scenarios proximity to the Ray Street bridge scenario represented in fig.8 above. This demonstrates how UUMI can change within very short distances. **Source:** London Underground Ltd. *Plan ©TfL; © Crown Copyright and database rights 2017 Ordnance Survey 1000035971.*

Fig.11: satellite image showing a closer holistic view of the scenario in question, a building located over UUMI. Note how the railway is in cutting, with public highway either side, a bridge to the south (left), and the building itself located over the railway. **Source:** Bing Maps

Fig.12 photograph showing 54 Farringdon Road, located over the sub-surface Metropolitan line tunnel, which on approaching the tunnel is in an open cutting. To the bottom right, below the Metropolitan line is the Network Rail Thameslink route.

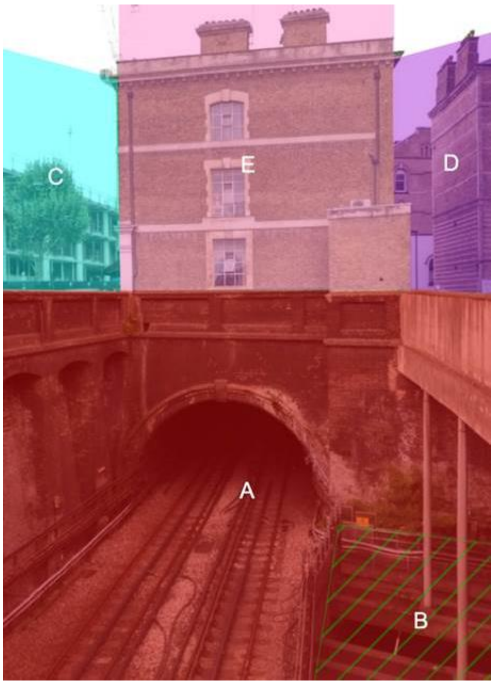

Fig.13 photograph showing 54 Farringdon Road, located over a sub-surface railway tunnel. A = London Underground land and airspace; B = Network Rail land and airspace (below); C = TfL Streets highway; D = Local authority highway; E = Building owner. **Source:** ***photograph*** - Nathan Darroch; ***property data*** – TfL, undated(c).

was subsequently sold in 1969, excluding the interests of London Transport (marked ‘A’ and ‘B’ on fig.13; Land Registry Title and Plan: NGL105699). (London Transport was the successor to the Metropolitan Railway and predecessor to London Underground).

In 1979, what is now the Network Rail Thameslink route (indicated ‘B’ in fig.13) was re-vested in to British Railways, a predecessor company to Network Rail (Vesting Agreement, 1979). This was to enable electrification and improvement to services on the route. London Transport, retained the Metropolitan line and: the tunnel under the building; the bridge carrying the Metropolitan line over the Network Rail line; the retaining walls supporting the adjacent public highways; and the building to the right, supported off LU owned girders, below ‘D’, and above ‘B’. Re-vested in to British Rail, and now owned by Network Rail, were the airspace below the LU structures, through which the main line trains pass, and the tunnel north of and adjacent to the LU tunnel beyond this location. The public highway to the right at ground level and marked ‘D’ is managed by Islington Borough Council; the public highway to the left at ground level and marked ‘C’ is managed by TfL. In both instances the retaining walls below and supporting the foundations of the public highways are owned by LU.

Protection: To ensure the continued safe presence and operation of the UUMI and its urban environment, each asset manager (LU/Network Rail/building/highway), must have a clear *knowledge* of what they are responsible for to inspect and maintain, and why. They must also have an *understanding* of how it interfaces with its environment (*presence*). In addition, if any party wishes to make any changes to, or undertake works on, their own assets and infrastructure, they must do so in such a way as to not adversely affect their neighbours. Again, this requires a detailed *knowledge* of what they are responsible for, what they have a right to do, and why. They must also have *knowledge* of how these changes may affect their environment (*property*). To achieve this and mitigate risk, a clear understanding of what is proposed and how these changes will be undertaken must also be developed, communicated to, and agreed with the other interfacing parties. Not just from the physical perspectives, but also those of property (Crossrail, 2016; TfL, undated(c); MTR, 2014) (*future proofing*). Failure to do so could result in a further incident such as that in RAIB, 2014.

4.2 Findings of the case study

The *presence*, of urban infrastructure, whether surface or sub-surface, can remain the same or change over short and extended distances and periods of time. For example, consider how figs.7 and 10 both show the *presence* of a variety of different railway formations within a limited areas and distances. With regard to both, there are separate periods of *physical* change not only to the environment of the UUMI, but the UUMI itself. For example, in fig.10 there was the construction: of the Metropolitan line (opened 1863); what is now Thameslink (1867); and 54 Farringdon Road (mid-1870s). However, little has changed to the environment *physically* since, except the provision of a new building over the Network Rail girders at an undetermined time, but possibly late 20th century. This lack of change is arguably because of the *presence* of the UUMI and the difficulties of developing over, and around it cost effectively, especially when compared with the other examples within this paper (figs.2, 5, 7, 9, 12, 14, 15) (Darroch, 2012; Darroch 2014; Darroch, et al.2016).

What has changed most however, are the *property* aspects of *ownership, rights, and responsibilities*. This was primarily caused by socio-political influences (changes in government and policies) through *legislation* (Butcher, 2012). For example, the transfer of 54 Farringdon Road to the Surplus Lands Committee and its subsequent re-vesting. These are issues relevant today with demand for more urban space and effective use of all land and airspace within that environment (Gov.uk, 2017; GLA, 2018; WSP, 2017(b)). However, change of ownership to railway infrastructure, whether driven through socio-political demands or because of improvements to technology and services can and potentially does cause complicated relationships within these environments. These interfaces require very clear appreciation, understanding, and knowledge to effectively ensure the sustainability and resilience of the metro and urban infrastructure.

While constant, the interface of *protection is* perhaps partially dormant. It is not just about managing change (urban redevelopment) but also managing the assets and their environment while they are operating. For example: cleaning of windows; repairs to walls or roads; or to the railway track itself. Stakeholders must therefore pro-actively *future proof* their own continued safe presence and operation of their assets, through ongoing inspection and repair. But to do this they must ensure a clear understanding and knowledge of what is there (*presence*); what they own and what they are responsible for (*property*). And when the works or changes to assets are undertaken, they are done so without adversely affecting those of their neighbours in the short or long terms (*protection*).

In all instances of the primary interfaces, it was clearly identifiable that no *one* primary interface exists or operates by itself. Each is influenced by and influences the others. Only by applying the sub-interfaces/enablers can a greater understanding and knowledge of how, when and why, and what may be, can the effective management of the respective UUMI and its urban environment be undertaken.

5.0 Applicability and transferability

The purpose of this paper was to present the findings of ongoing research in to the interfaces between UUMI and its environment. But the principles are also applicable to the planning, design, and management of other types of urban underground space and their environment. In this respect, it is not the *micro* detail of what the UUS is used for that is most relevant, but the *macro* and *holistic* considerations of what is present, who owns it, and how must it be protected that is key. For example, compare figs.14 and 15. One, extracted from a professional journal paper on the development of the British Library, near Kings Cross station in London (fig.14); the other a tower block in Osaka, Japan (fig.15).

Fig.14 shows how the 1980s constructed British Library, in London, was designed to accommodate two periods of tube railway development: the Northern line (1900s), and the Victoria line (1960s). The building cantilevers over the tube tunnels, with different foundations for the two sections of the building: raft over the tunnels and piles to the side of the tunnels (Simpson and Vardanega, 2014*)*. The ownership of the land surrounding the tunnels is that of the British Library, whilst the tunnels themselves are owned by LU, within the subsoil of the library (TfL, undated(c)). This scenario is reflective of 54 Farringdon Road, with assets of one party within the subsoil or land of another party. Fig.15 shows a high-rise building in Osaka, Japan (Morrison, undated). The public highway is owned by the local authority, the building by a private party. Note how the highway passes through two floors of the building, not just the physical structure of the highway, but the airspace above it which enables the passage of vehicles. Also note how the physical structures appear to be

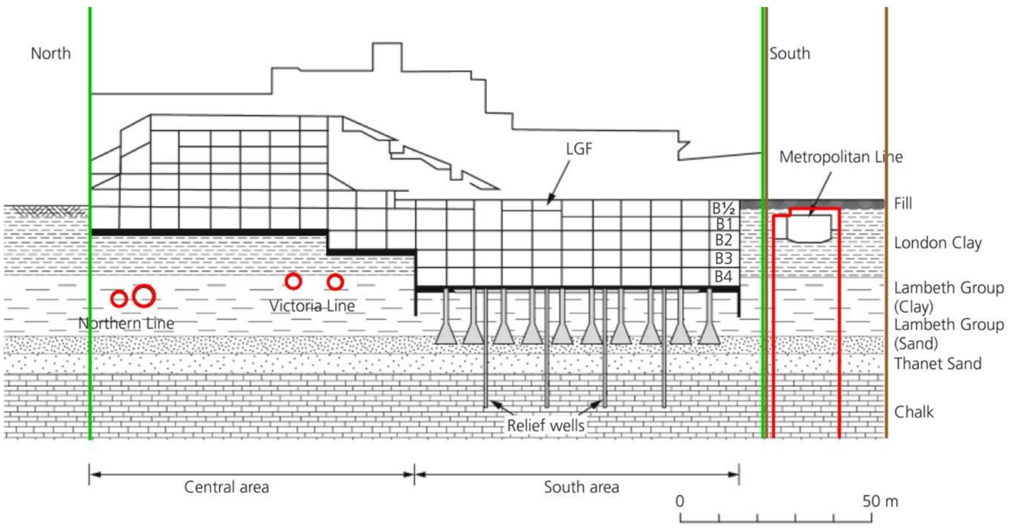

***Fig.14**: extracted diagram from Simpson, B., and Vardanega, P., 2014, showing how the British Library is designed to accommodate the presence of the older UUMI. The diagram has been modified to also show the property boundaries between the various stakeholders within the area. Red = LU UUS/UUI and subsoil; green = the British Library; brown = local highway authority.*

***Fig.15**: 'In Osaka, Japan There's A Highway That Goes Through A Building'. Is this scenario any different from the primary interfaces of UUMI? **Source:** Morrison, G., undated.*

independent of one another whilst within the same overall footprint. The conceptual framework can be applied to both examples to understand how and why the interfaces between the collected assets occur, just as effectively as with UUMI or UUS.

6.0 Conclusion

Urban environments are based on the actions of the past and have an historical perspective. Therefore "if *historical geography is about understanding how the 'past shapes the geographies of the present and the future', it must be used to advise and guide those managing and planning the urban environment,* ***and*** *its transport infrastructure, now and in the future"* (Darroch, 2018).

As with any life cycle of an asset, time is an essential consideration. Urban environments change as do assets within those environments. This environmental change must be effectively managed by understanding what is within it; who owns it; and how it must be protected, at proposal, planning, design, construction, operational, and replacement stages. This is an essential consideration for the collective whole life asset management of urban underground space/infrastructure *and* its environment. The consideration of these interfaces varies between urban stakeholders. An urban planner does not need to understand the detail (*micro*) of the interfaces. They do need to know what is present *holistically*. They can then advise an urban developer to contact the asset *owner* if there is a potential risk to within the development area. Through that advice, the developer and asset manager could then undertake *macro* and *micro* analyses of the proposed urban change and how it may affect existing infrastructure. Methods can then be prepared and enacted to ensure the protection and safe ongoing presence and operation of that infrastructure while its environment is changed. However, currently, there appears to be little consideration of these issues beyond proposal stage for urban underground space.

This paper has presented an overview of continuing research for the development of a conceptual framework to assist identification and clarification of these interfaces. It has introduced three levels of analysis to be undertaken using the conceptual framework, each level applicable to a different stakeholder in urban asset management. It has argued, that these three levels of analysis, and understanding of the three primary interfaces of UUI (*presence, property, and protection*) and its environment are essential to the effective management of current and future cities. To demonstrate this argument three sample scenarios were presented at *holistic*, *macro* and partial *micro* levels. A simplified case study was also presented, concentrating on a building located over a railway tunnel, with another railway tunnel subjacent. What these showed is that the interfaces between UUS, represented by UUMI, is not always simple and may even not be fully appreciated. This especially seems to be the case within the current literature and proposals for development of UUI. With greater appreciation of the interfaces there would be more balanced discussion and benchmarking of processes of these interfaces and how they have a very important effect on their environment. But to understand how presence, property, and protection may affect the future of cities, historical consideration of what is present and how it affects its environment, now, must be considered at *holistic*, *macro* and *micro* levels.

Readers may be of the opinion that they already follow the undocumented principles of the conceptual framework and workflow. Through the authors' research and professional experience the complexities of presence, property, and protection are not clearly discussed or benchmarked within academic or professional literature/standards/policies/or procedures, though it may be undertaken in practice. Nor are the levels of appreciation, understanding, and knowledge, required by different stakeholders, appropriately documented/discussed/or benchmarked.

Whether metros are currently existing; are being built; are undergoing establishment of Public Private Partnerships (PPP); or have had failed PPP in the past; the principles of the conceptual framework are paramount to effective asset management, now and in the future. To achieve efficient identification and clarity of asset presence, property, and protection, the authors believe it is essential to identify one common (international) understanding of these concepts, through written discussion, benchmarking, standards, policies, and procedures. Not just for UUMI, but UUS, its related UUI, and its urban environment.

The findings of this paper present a challenge to current practice in terms of whether current strategies and proposals for the development and management of urban underground space, and its environment, are fit for current and future demands and changes. The principles proposed in this paper are offered as a means to assist identification and clarification of how existing and proposed urban underground space interfaces with its environment, something which appears to be currently lacking.

6.1 Continuing research

The continuing research, while concentrating on *macro* analyses, will include some *micro* analyses. This will be applied to three primary case studies taken from the sample scenarios described in Section 3. These will consider the primary interfaces at three locations in detail: Smithfield Market; Bank; and Westminster. Within each location there are three sample scenarios: tunnel under highway; metro infrastructure within a building; metro infrastructure under a building. These were identified as most indicative of UUMI globally through a review of literature on other metro systems worldwide; the Glasgow pilot study (Darroch et al, 2016); and a survey distributed through the Community of Metros (CoMET, 2018) in 2015/2016. In addition, the lead author undertook a research trip to Metropolitano de São Paulo, Brazil, in May 2018, to apply the conceptual framework to that metro system. The findings of this research will be the subject of a thesis to be presented in 2019.

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