Building Adaptation in the Melbourne CBD: The relationship between adaptation and building characteristics.

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SUMMARY

In the attempt to mitigate climate change and global warming, there is an increasing realisation that large scale programmes adapting existing buildings is a viable means of reducing building related greenhouse gas emissions (CSIRO, 2002 AECOM 2008). Buildings contribute around half of all greenhouse gas emissions (BRE, 1996), and Australian offices alone account for 12% of all greenhouse gas emissions. The City of Melbourne has launched the 1,200 building program which aims to refurbish 1,200 CBD properties before 2020 as part of their policy to become a carbon neutral city by 2020. A number of questions arise such as; which buildings are most suitable for adaptation? What can we learn from the previous patterns of building adaptation? Which buildings are more likely to undergo adaptation? Furthermore is there any relationship between specific building attributes or characteristics that make them more ‘adaptable’ than others.

This paper addressed the question; *What is the identity and nature of the relationships between building adaptation events in the CBD and building attributes?* The research uses the Melbourne CBD as a case study. The research reports on the patterns of adaptation, the type and extent of building adaptation over a ten year period from 1998 to 2008. All adaptation events that occurred during this period are included in the study making the study the most extensive and comprehensive analysis of building adaptation undertaken in Australia. The outcomes of this research is applicable on a global basis and relevant to all urban centres where existing commercial buildings can become part of the solution to mitigate the impact climate change and enhance the city.

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INTRODUCTION

This paper addresses the research question;

1. *What is the identity and nature of the relationships between building adaptation events in the CBD and building attributes?*

The emphasis was placed on the extent and nature of the relationships between the previously identified building adaptation events in the Melbourne CBD between 1998 and 2008 and building adaptation attributes identified in the literature as being important decision making factors. Previous studies were limited in respect of the total number of cases or buildings that informed their research. This study overcomes this limitation as *every* building adaptation event that ocurred between 1998 and 2008 within the Melbourne CBD is included.

FACTORS INFLUENCING BUILDING ADAPTATION

Douglas's 2006 definition of adaptation is adopted for the research; that is "*any work to a building over and above maintenance to change its capacity, function or performance' in other words, 'any intervention to adjust, reuse, or upgrade a building to suit new conditions or requirements"*. Previous research into building adaptation has identified and grouped the determining factors under categories of economic, social, environmental, technological, legal and physical (Wilkinson et al, 2009). Readers are referred to the Wilkinson, James and Reed paper (2009) for a full discussion of the nature and extent of the factors influencing adaptation.
Ball (2002) noted the local economy is a contributing factor for adaptation, along with the characteristics of buildings such as age and physical condition, perceived heritage value, size (i.e. smaller buildings were more marketable), accessibility and user demand (Fianchini 2007). Ball's (1999) study concluded that building quality and character were determinants of successful adaptation. Fianchini's (2007) study of adaptation in Italian education stock found accessibility to be a critical success factor, along with layout, flexibility for a range of differing uses. Barras (1996) showed a relationship between building age and obsolescence in London offices.

Gann and Barlow (1996) showed the technical issues in adapting offices to residential use were; building size and height; depth; structure; envelope and cladding type; internal space layout and access; services; acoustic separation and fire safety. Other attributes were site (e.g. orientation, external noise, car parking and external access), size (e.g. total floor area, height, depth, floor shape, grids, and floor to ceiling height), structure (e.g. penetration for services), envelope (e.g. cladding and thermal issues), services (e.g. to meet new use requirements), acoustic separation (e.g. floors and partitions, flanking transmission) and fire protection (e.g. means of escape, brigade access, detection and alarms, prevention of spread of flames). Each of the physical attributes impact on the adaptation potential and should be considered in decision making.

Location is often cited as an important criterion for adaptation (Ball, 1999). Many older buildings occupy prime locations (Ball, 2002. Industrial buildings built next to canals and rivers benefit from the desirability and value associated with 'waterfront views'. Ellison and Sayce (2007) noted that within the paradigm of sustainability, location can be interpreted as accessibility to the building's user group and therefore transport nodes such as rail and bus transport systems add to the desirability of a property for adaptation. Table 1 summarises the adaptation attributes identified in previous research

Table 1: Summary of building adaptation criteria.

Adaptive reuse criteria for existing buildings	**Relevant research study**
Age	(Barras and Clark 1996; Ball 2002) Ball, 2002; Fianchini, 2007
Condition	Boyd et al 1993; Isaacs (in Baird et al) 1996; Swallow, 1997; Snyder, 2005; (Kersting 2006)
Height	Gann & Barlow, 1996.
Depth	Gann & Barlow, 1996; Szarejko & Trocka-Lesczynska, 2007.
Envelope and cladding	Gann & Barlow, 1996.
Structure	Gann & Barlow, 1996; Kersting, 2006
Building services	Gann & Barlow, 1996; Snyder, 2005; Szarejko & Trocka-Lesczynska, 2007.
Internal layout	Gann & Barlow, 1996; Swallow, 1997; Fianchini, 2007; Szarejko & Trocka-Lesczynska, 2007
Flexibility for a range of differing uses and functional equipment	Gann & Barlow, 1996; Fianchini, 2007
Location	Isaacs (in Baird et al) 1996; Bryson, 1997; Ball 1999, 2002; (Remoy and van der Voordt 2006)
Perceived heritage value	Ball, 2002. Snyder, 2005.
Size	Gann & Barlow, 1996. Ball, 2002.
Accessibility	Gann & Barlow, 1996. Ball, 2002. Snyder, 2005. Kersting, 2006. Remoy & van der Voordt, 2006. Fianchini, 2007. Ellison and Sayce, 2007.
Proactive policy making / legislation (planning and building codes including fire)	Chudley, 1981; Gann & Barlow, 1996; Highfield, 2000; Heath, 2001; Ball, 2002; Listokin and Hattis, 2004; Snyder, 2005; Burby et al, 2006;

	Kersting, 2006; Galvan, 2006; Shipley, 2006.
Acoustic separation	Gann & Barlow, 1996.
User demand	Ball, 2002.
Site conditions	Isaacs in Baird et al, 1996.

(Source: Author)

RESEARCH METHODOLOGY

Many studies have examined the criteria for building adaptation; overwhelmingly the researchers have adopted a case study approach based on in depth analysis of a relatively limited number of cases (Barras and Clark 1996; Ohemeng 1996.; Blakstad 2001; Heath 2001; Ball 2002; Kincaid 2002; Kucik 2004; Arge 2005; Remoy and van der Voordt 2007). From these research studies adaptation criteria for this study have been identified, however the approach developed is fundamentally different from this point forward.

The research was undertaken in two stages. Stage one examined building adaptation criteria identified by the authors above and summarised in Table 1. These criteria formed the fields for the building attribute database.

Table 1: Criteria for Adaptation Database fields

1. Building ID number 2. Cityscope Code 3. Map Number 4. Property Number 5. Unit Number 6. Building Name 7. Street Address 8. Street Number 9. Street Name 10. Street Frontages 11. Description. 12. Historic Listings 13. Proposals 14. Number of floors 15. Year built 16. Year refurbished / adapted 17. Number of refurbishments / adaptations Extent of adaptation.	23. Occupancy type – sole occupier, multiple occupants, vacant 24. Zoning 25. GFA 26. NLA 27. PCA Grading. 28. Type of construction. 29. Plan shape. Elasticity potential – lateral extension Elasticity potential – vertical extension 30. Site boundaries. Site access to building. 31. Tenure - institutional / private /government /	39. Green roof option 40. Aesthetic qualities 41. Building envelope type 42. Building envelope condition 43. User demand 44. Site orientation 45. Internal layout 46. Column arrangement 47. Vertical services location 48. Floor size 49. Cost in use profile – gross income 50. Cost in use – statutory charges 51. Cost in use – operating expenses 52. Electricity consumption by

18. Parking 19. Number of car bays 20. Site Area 21. Total Building Area 22. Occupant classification - owner, lessee, vacant.	educational. Proximity to transport 32. Greenstar rating 33. NABERS rating 34. ABGR rating 35. Proactive legislation 36. Hostile factors 37. Roof overshadowing 38. PV option	PCA Grade 53. Gas consumption by PCA grade 54. Water consumption by PCA grade

(Source: Author)

The researcher designed and compiled a building attribute database of commercial buildings in the Melbourne CBD to collect data based on the previously identified building adaptation criteria. The database is populated with data from numerous sources; such as a commercially available database Cityscope (RPData 2008), the PRISM database produced by the State Government of Victoria's Department of Sustainability and Environment (DSE 2008) and through commercial data produced by the Property Council of Australia (PCA 2007; PCA 2008). Empirical data was gathered by the researcher visually surveying the buildings. The primary researcher is a Chartered Building Surveyor with over 23 years post qualification experience and this assisted the research process. The Building Attribute database included variables listed in Table 2. These variables have been categorised as physical, social, legal, economic and environmental characteristics or attributes of adaptation.

RESEARCH POPULATION AND SAMPLING

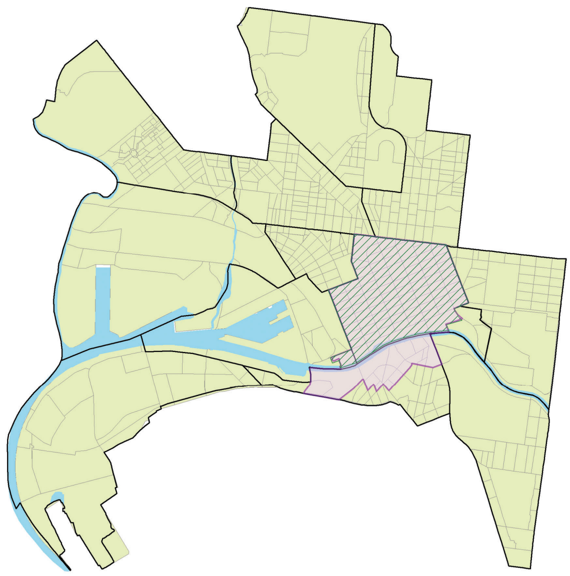
Much research samples the research population, where the goal is to target a representative sample of the population so that results have external validity (Naoum, 2000). Sampling involves deciding on which technique to adopt to capture a representative group. It is possible for sampling to go awry because of respondent apathy and access issues and the survey and interview approach was deemed high risk and rejected here. The risk of an unrepresentative sample was avoided through the adoption of a census approach, uniquely this research examines *every* building adaptation event within the Melbourne CBD between 1998 and 2008. A total of 13222 building adaptation occurred between 1998 and 2008 in the CBD and each one was recorded in the database complied for the study.

DEFINING THE MELBOURNE CBD AREA

A challenge was to define the geographic area for the study. This research focused on the analysis of building adaptation events over time and sought to investigate activity in a well developed, mature commercial market.

The CBD was the first area laid out in Melbourne in 1834, it has been continuously occupied and is the most mature property market in Victoria. It has evolved and changed from the 1830s and it was necessary to consider current definitions of the CBD before defining the area for the study. The CBD area used in this research is highlighted within the diagonal cross hatching in figure 1. This research focused on the orginial grid laid out by Hoddle. The streets within the CBD area for this research are as Flinders Street (southern boundary), Spencer Street (western boundary), Spring Street (eastern boundary) and La Trobe Street (northern boundary).

Figure 1 –City of Melbourne Map



PRINCIPAL COMPONENT ANALYSIS (PCA).

PCA is a reliable and proven method of highlighting dimensions in cross sectional data (Horvath, 1994) with the capacity to uncover, disentangle and summarise patterns of correlation within a data set (Heikkila, 1992). The purpose of PCA is to condense information contained in a number of original variables into a smaller set of new composite factors with a minimum loss of information (Hair et al, 1995). PCA was used to reduce the dimensionality of office building attribute data relating building adaptation in the Melbourne CBD between 1998 and 2008.

With PCA there is no underlying statistical model of the observed variables and the focus is placed on *the explanation of the total variance* in the observed variables (Tabachnick & Fidell, 2001). PCA is well suited to hypothesis testing as it can simplify complex data by finding the minimum number of dimensions that can be used to describe them, without leaving a large amount of variance unexplained (Sappsford & Jupp, 1996). Its contribution to this research is centred on its ability to provide a unique solution with each component in turn accounting for decreasing variance.

When beginning an analysis the initial step is to enter all the variables in to the PCA and produce a smaller number of factors. The next decision is based on the actual number of factors to retain in the analysis as the PCA produces an equivalent number of factors to the original number of variables originally entered. In the analysis this retention decision was based on the Kaiser criterion where factors with eigenvalues exceeding 1.0 were retained for further analysis. The factors were then rotated using an oblique rotation method known as Oblim rotation. The final result produced a condensed table of identifiable factors and included details regarding the loadings of individual building attributes associated with each factor. Thus the contribution of a building attribute variable to each factor could be; completely positive (+1.0), completely negative (-1.0) or somewhere between the two.

Assigning meaning to a PCA solution involves substantive interpretation of the pattern of the factor loadings, and a minimum acceptable level of threshold for individual building attribute variables must be ascertained prior to the interpretation (Hair et al, 1995). After analyzing the level of loadings across the factors, the threshold cut off was set relatively high at 0.6 as recommended by Tabachnick & Fidell (2001). It has been shown that variables with loadings exceeding 0.55 are important (Comrey & Lee, 1992 as cited by Tabachnick & Fidell, 2001) and the threshold adopted in this analysis exceeded this level.

After a list of individual factors had been assembled where each factor contained high loading building attribute variable equal to or exceeding 0.6 suggested correct factor names could be assigned. The individual names allocated to each high loading factor in a PCA were at the researcher's discretion and subject to each individual researcher's individual interpretation. This process is subjective and may result in multiple and confusing names for individual but similar factors. Most of the factor names in this analysis were straightforward and readily allocated. In the process of assigning names consideration was given to the factor names used in previous studies and how these high loading variables had been interpreted.

INITIAL PCA - AGGREGATE BUILDING ACTIVITY

The database for the initial analysis commenced with all available Melbourne CBD office building adaptation events from 1998 to 2008 that were accompanied by building attribute data. The role of the initial analysis was to analyse all events from minor to major. The PCA reduced the dimensionality of the dataset into a smaller number of factors as represented by factor scores. Only factors with eigenvalues exceeding 1.0 were retained, where eigenvalues represent the extracted variance associated with each variable (Tabachnick & Fidell, 2001).

7,393 building events occurred between 1998 and 2008 in the Melbourne CBD to commercial buildings for which full address details could be determined. There were other events but due to omissions, the full address for these properties could not be determined and data relating to physical building characteristics could not be collected and these cases were omitted from the analysis. The total number of adaptation events between 1998 and 2008 was 13,222 however complete building identification data existed for 7393 cases, 55.91% of the total events.

LIMITATIONS OF PCA

No approach is without limitations and researchers must attempt to minimise limitations where possible. There are three main limitations associated with PCA (Tabachnick & Fidell, 2001). Compared to a multiple regression approach with its dependent variable, PCA has no external criterion, against which the solution can be tested and this is a weakness. Secondly after extraction an infinite number of rotations are available and the final choice depends on the researcher's subjective assessment, subsequently the results can be argued and challenged (Tabachnick & Fidell, 2001). Given the researcher's first-hand experience of building adaptation as a professional practitioner and her experience as a researcher, this weakness is minimised as far as possible. Furthermore triangulation of the researcher's results with previous studies further diminishes this limitation of PCA. Finally poorly conceived research will result in weak and indefensible results and the research has been diligently planned and executed at every stage to produce the most reliable and valid results possible using PCA.

PCA PROCEDURE

The final database comprised 54 variables for each adaptation event (table 1), although many variables were building identification numbers, address details and so forth. The data was exported from Excel format into SPSS version 17 for the PCA analysis. The variables in this research were building attributes and characteristics associated with building adaptation events to commercial buildings. The key steps in a PCA were as follows;

1. Extract the components
2. Decide how many factors to retain
3. Rotate the factors
4. Interpret the factors
5. Create factor scores

Factor analysis is an exploratory technique where the objective is to view the data in different ways. The goal of PCA is to reduce this large number of variables down to a smaller number of components which can be interpreted. A good PCA 'makes sense', whereas 'a bad one does not' (Tabachnick & Fidell, 2001). Researchers often undertake a number of analyses using different methods of extraction or retaining different numbers of factors before finding a set of factors which can be interpreted. PCA is a unique mathematical solution and an empirical summary of a dataset; here the building attribute building adaptation event database compiled by the researcher.

STEPS 1 & 2 - EXTRACT THE FACTORS (TO BEGIN EXTRACT AS MANY FACTORS) AND DECIDE HOW MANY FACTORS TO RETAIN.

Table 3 shows the variables used in the initial analysis of all building adaptation events.

Table 3. Variables used in PCA of all adaptation events in Melbourne 1998 – 2008

1. Building work type	2. Total Building Area
3. Nature of work (redevelopment or adaptation)	4. Occupant Classification (owner/lessee/vacant)
5. Plan shape	6. Typical Floor Area
7. Purpose built for current use	8. Occupancy (sole/multiple/vacant)
9. Purpose built commercial	10. Zoning
11. Site orientation	12. GFA
13. Aesthetics	14. NLA
15. Internal layout (space plan)	16. PCA grade
17. Internal layout (columns)	18. Type of construction
19. Vertical services	20. Elasticity potential vertical flexibility
21. Existing land use	22. Site boundaries
23. Floor size	24. Site access
25. Street frontage (metres)	26. Tenure type
27. Site area (sqm)	28. Property location
29. Historic listing	30. Green Star rating
31. Number of Storeys (height)	32. NABERS rating
33. Age in 2010	34. ABGR Rating
35. Year Built	36. Building envelope and cladding
37. Parking	38. Hostile factors
39. Number of Car Bays	40. Elasticity potential lateral flexibility
41. Proximity to transport	42. Tenure type

(Source; Author)

Initially the PCA would not compute because either there were fewer than two cases, or at least one of the variables had zero variance and there was only one variable in the analysis, or the correlation coefficients could not be computed for all pairs of variables. A series of different PCA iterations were run using SPSS with a different variable omitted on each occasion to determine a reliable statistical analysis.

In SPSS version 17 the following parameters were established for the PCA. To produce a table of correlation coefficients, the descriptive box was selected and initial solution selected. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity was selected and as KMO score of greater than 0.5 is considered acceptable and for the Bartlett test a significance of less than 0.05 for cause for further factor analysis. After each PCA iteration individual variables were removed and or reintroduced until a KMO and Bartlett's test were calculated. With each PCA iteration, the researcher sought to derive the highest KMO score along with the highest possible cumulative percentage for the total variance explained. In thirty three successive PCA iterations the following variables were sequentially removed from the analysis;

Table 4. Variables removed from initial PCA of all building events in Melbourne 1998 - 2008

1. Nature of work (redevelopment or adaptation)	2. Elasticity potential lateral flexibility
3. Purpose built for current use	4. NLA
5. Purpose built commercial	6. Type of construction
7. Plan shape	8. Tenure type
9. Site orientation	10. Green Star rating
11. Internal layout (space plan)	12. NABERS rating
13. Floor size	14. ABGR Rating
15. Site area (sqm)	16. Building envelope and cladding
17. Year Built	18. Hostile factors
19. Number of Car Bays	20. Zoning
21. Total Building Area	22. Tenure type
23. Occupant Classification (owner/lessee/vacant)	24. Occupancy (sole/multiple/vacant)
25. Proximity to transport	

(Source; Author)

The PCA with the highest KMO score and highest degree of total variance explained contained the variables shown in table 6 below.

Table 5. Variables used in the final PCA of all building events in Melbourne 1998 – 2008

1. Site boundaries	2. NLA
3. Internal layout (columns)	4. Typical Floor Area
5. Vertical services	6. GFA
7. Existing land use	8. PCA grade
9. Street frontage (metres)	10. Site area
11. Historic listing	12. Plan shape
13. Number of Storeys (height)	14. Site access
15. Age in 2010	16. Property location

(Source; Author)

For the variables above the KMO score and Bartletts test are shown below;

Table 6. KMO and Bartlett's Test PCA All adaptation events
KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.699
Bartlett's Test of Sphericity	Approx. Chi-Square	9715.643
	df	120
	Sig.	.000

(Source; Author)

With the KMO of 0.699 exceeding 0.50 and the significance less than 0.05, the PCA was continued. SPSS allows several methods of extracting factors and determining how many to retain. The researcher adopted the principal components option. In the number of factors to retain box no entry was selected as the research is exploratory in nature and does not seek to examine a pre-determined number of factors in the analysis.

A scree plot helps to visualise where the change occurs between variables having an effect and those forming the main 'scree' at the base which have limited effect (Tabachnick and Fidell, 2001). As Tabachnick and Fidell (2001) noted interpretation of the scree plot is subjective. Sixteen variables were analysed and the scree plot showed a flattening after the third component where the Eigenvalue changes from 1.753 for the third component to 0.605 for the fourth component. This suggests that three variables have had the highest effect on CBD building adaptations between 1998 and 2008.

STEP 3 – ROTATE THE FACTORS.

The next stage is to rotate the factors, and a choice is made between orthogonal or oblique rotation. The motivation behind rotation is to find the meaning of the factors that underlie responses to observed variables. Although orthogonal rotation is 'easier to interpret, report and describe results'; it is said to strain reality unless the researcher believes the underlying processes are almost independent which is not the case with building adaptation attributes and events (Tabachnick & Fidell, 2001). Oblique rotations are used where the underlying processes are correlated, although they are considered more difficult to interpret. Tabachnick and Fidell (2001) noted that oblique rotation offers a continuous range of correlations between factors providing 'an embarrassment of riches' for the researcher. This research sought to ascertain correlations between factors and the Direct Oblim, being 'oblique' in nature allow this to be determined (Francis 2007). For example the researcher sought to determine if say the variables of historic listing and age were correlated in building adaptation events. The Direct Oblim rotation was selected.

Finally the researcher addressed the matter of missing values and the way in which the coefficients were displayed. In the 'Options' dialogue box in SPSS, the researcher decided not to view very small coefficients of less than 0.10 and this option was selected. In the Missing values option the exclude cases list-wise was chosen. The total variance explained table is divided in to three sections (table 7).

The first heading under Initial Eigenvalues shows the variance explained by each of the 16 components extracted by principal component analysis (Hinton, Brownlow et al. 2004). In the second section the variance explained by three components is shown. Overall three factors explain 87.87% of the original variance. Note that the fourth factor has an Eigenvalue of .604 which is less than 1, and using the Kaiser's criterion three factors is retained. The third section, headed rotation, shows the Eigenvalue of each of the three rotated components. Note that as the components are correlated with each other there is some overlap in the variance explained by each factor (Francis 2007). The total amount of variance explained by the three components cannot be obtained by adding the three eigenvalues. For the rotated solution the factor loadings (standardised partial regression coefficients) are given in the table headed Pattern Matrix (table 8 below) and correlations are given in the table headed Structure Matrix (see table 9).

Table 7. Total Variance Explained PCA All adaptation events

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	9.920	61.997	61.997	9.920	61.997	61.997	8.428
2	2.388	14.924	76.921	2.388	14.924	76.921	4.186
3	1.753	10.956	87.877	1.753	10.956	87.877	5.613
4	.605	3.781	91.658				
5	.494	3.085	94.743				
6	.338	2.115	96.857				
7	.170	1.064	97.921				
8	.120	.753	98.675				
9	.077	.479	99.154				
10	.060	.374	99.528				
11	.051	.321	99.850				
12	.014	.090	99.940				
13	.008	.047	99.987				
14	.002	.010	99.996				
15	.000	.003	99.999				
16	.000	.001	100.000				

Extraction Method: Principal Component Analysis.

a. When components are correlated, sums of squared loadings cannot be added to obtain a total variance.

(Source; Author)

In oblique rotations the meaning of factors is derived from the pattern matrix which shows the unique relationships (uncontaminated by overlap among factors) between each factor and each observed variable (Tabachnick & Fidell, 2001). Table 8 shows the three components and their variables colour coded for this PCA.

Table 8. PCA All adaptation events Pattern Matrix[a]

	Component		
	1	2	3
1. historic listing	.993		
2. age in 2010	-.944		
3. internal layout - columns	-.895		.161
4. Typical Floor Area	.879		
5. site boundaries	.816	.131	.230
6. street frontage (metres)	.789	-.390	-.202
7. site area (sq m)	.635		.529
8. vertical services location		.970	.186
9. plan shape	-.139	.860	
10. existing land use	.194	.780	-.267
11. PCA grade	-.426	.568	-.335
12. property location	.249		-1.028
13. NLA	.549		.648
14. Number of Storeys	.492	-.113	.648
15. GFA	.552		.628
16. site access	.410	-.172	.583

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

a. Rotation converged in 13 iterations.

(Source; Author)

Factors defined by less than 3 variables are deemed to be unreliable (Francis 2007) – therefore in this analysis, all three components may be considered reliable, having seven, four and five variables respectively. The next stage in the analysis and a condition of PCA is to determine whether it is possible to interpret the factors.

FACTOR INTERPRETATION & ANALYSIS

FACTOR 1 ANALYSIS

In the rotated solution the variables; historic listing, age, internal layout (columns), typical floor area, site boundaries, street frontage and site area are very strongly (.993) to strongly (.635) loaded on factor 1 9 (see table 8). Factor 1 has seven variables (table 10) which is a high number to group. Six of the seven relate to the physical attributes of property in terms of age, internal layout featuring columns (which is also related to size), size (floor area, street frontage and site area) and finally with site boundaries, the degree of attachment to other buildings. Age and internal layout are negative loaded which means as buildings age and with the presence of columns more adaptation is undertaken. The remaining variable relates to whether the property is listed or not (which can be either a social or regulatory attribute). In summary it is possible to refer to these attributes as 'social/physical'. Though outnumbered by purely physical attributes historic listing has the highest score (table 8).

Table 10. Factor 1 Analysis – Social / Physical

Variable	PCA Loading
1. Historic listing	.993
2. Age in 2010	-.944
3. Internal layout - columns	-.895
4. Typical Floor Area	.879
5. Site boundaries.	.816
6. Street frontage	.789
7. Site area	.635

(source: Author)

FACTOR 2 ANALYSIS

In the rotated solution four variables (vertical services location, plan shape, existing land use and PCA Grade) are positively and very strongly to strongly loaded (.970 to .568) on factor 2.
Vertical services location and plan shape, the first two variables, could both be interpreted as 'configuration of space' within the building / site. The physical location of building services are of considerable importance within commercial property and building services more so than other building components have shorter life cycles (up to 20 years) and become outdated and worn is shorter time frames, thereby triggering a higher rate of adaptation. In comparison building frames are deemed to have life cycles in excess or 80 years.

Plan shape relates to physical shape of the building and generally speaking, complex plan shape are less easily to adapt whereas standard plan shapes easily sub divide and are cheaper to adapt on this basis. Both have been categorised as physical attributes in other studies. The existing land use variable is difficult to interpret easily, an acknowledged aspect of oblique rotation in PCA (Tabachnick & Fidell, 2001).

The land use variable relates to whether the land has a single commercial use or mixed uses; such as office and retail or office and residential. Properties with mixed land uses will be more expensive to adapt because they are more complex, involve more owners and more legislation. The fourth variable in factor 2 is PCA Grade and this can be seen as an economic attribute – property with a higher PCA Grade has more amenities and higher quality and therefore commands higher rental levels and greater capital values compared to lower grade alternatives. Equally it can be interpreted as physical amenity provision – PCA grade benchmarks a level of physical amenities in an office building. Although there is clearly a strong current of 'economic' influence in factor 2, this component is named 'Physical (configuration)'.

Table 11 Factor 2 Analysis – Physical (configuration)

Variable	PCA Loading
1. Vertical services location	.970
2. Plan shape	.860
3. Existing land use	.780
4. PCA Grade	.568

(source: Author)

FACTOR 3 ANALYSIS

The variables location, NLA, number of storeys, GFA and site access are very strongly negatively and positively (-1.028) to moderately loaded (.583) on factor 3. Variables with loadings exceeding 0.55 are important (Comrey & Lee, 1992 as cited by Tabachnick & Fidell, 2001) and site access passes this threshold adopted in factor 3.

Location is a physical attribute in the literature and is different to the remaining variables loaded on factor 3. The interpretation of this factor is that properties in prime locations undergo a greater frequency of adaptation which is logical as properties in prime locations needed to be refreshed and maintained up to the highest market standards in order to retain the highest rental and capital values in the CBD area. Conversely the properties in the fringe locations undergo less adaptation because the capital expenditure on the adaptation may not be recouped in increased rental yields or capital values.

Table 12. Factor 3 Analysis – design / economic

Variable	PCA Loading
1. Location	-1.028
2. NLA	.648
3. Number of storeys	.648
4. GFA	.628
5. Site access	.583

(source: Author)

NLA, number of storeys and GFA have been categorised as physical attributes in earlier research, however they all specifically relate to building size. These variables indicate that buildings of a certain size may undergo more or less frequent rates of adaptation and or greater or lesser degrees of adaptation. The last factor is related to building amenity –access to the site looks at the number of entrances or access points a building has from street level. The higher the number the greater the flexibility in terms of deliveries, staff entry and egress, the greater the ease of access to the property during physical construction / adaptation building works.

Factor 3 is complex and difficult to interpret easily; an initial name of 'physical (size)' has been ascribed to these attributes. Table 13 below summarises the main PCA component categories and the component names ascribed by the research interpreting the PCA.

Table 13. Summary of Main PCA Component Categories

Component number	Component name	Component variables
1	Social / physical	Historic listing Age in 2010 Internal layout - columns Typical Floor Area Site boundaries. Street frontage Site area
2	Physical (configuration)'	Vertical services location Plan shape Existing land use PCA Grade
3	Physical (size)	Location NLA Number of storeys GFA Site access

(Source: Author)

FINDINGS FROM MAIN PCA

There are two primary findings

1. This analysis reveals three defined interpreted factors.

2. The initial finding from this ‘all level’ analysis is that the PCA has correlated variables that previous studies identified as being quite separate and distinct (Blakstad 2001, Kucik 2004, Arge 2005, etc). Previous studies categorised variables distinctly into economic, physical, technological, environmental and legislative (regulatory) groupings, however the results of the analysis reveal that these groupings do not correlate strongly or well in this PCA. On this analysis it is apparent that the relationships between building adaptation attributes are far more complex than previously considered. One possible reason for this could be that a number of variables can be interpreted quite broadly; that is to say that the variable PCA Grade could be seen as one denoting the level of building amenity and quality, but equally PCA grade is an indication of rental yield and capital value and could be seen as an economic variable as well as an amenity variable.

CONCLUSIONS

This paper presents the results of a PCA of 7,393 building adaptation events in Melbourne CBD from 1998 to 2008. Statistically the data used in this research has fulfilled all the requirements of PCA for internal and external validity and reliability (Naoum, 2000). Initial findings indicate that previous studies of building adaptation may have adopted a more simplistic approach relying on a limited number of cases to investigate building attributes associated with adaptation. This research has taken a much broader investigation including economic, social, physical, technological and environmental variables to determine the identity and nature of the relationships between building adaptation events and building attributes. The research question has been answered through the PCA and the presentation of the 3 factors in the pattern matrix (table 8). The findings are that physical building attributes feature strongly within all factors which indicates physical attributes are more important than other attributes.

Within the 7,393 events there are different levels of building adaptation ranging from minor to major works as noted by (Arup, 2008) and Kincaid (2000). The different levels or types of building adaptation event will be analysed using PCA to determine whether there are differences between the different levels of adaptation.

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