Alterations and extensions to commercial buildings in the Melbourne CBD: The relationship between adaptation and building attributes

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Abstract

Arguably buildings contribute around half of all greenhouse gas emissions and Australian offices alone account for approximately 12% of all greenhouse gas emissions. As government authorities seek ways of reducing the contribution of cities to climate change and global warming on a global scale, building adaptation now appears as the only realistic means of reducing building related emissions by 38%. The 1,200 building program developed by the City of Melbourne aims to adapt or retrofit 1,200 central business district (CBD) properties before 2020 with sustainability measures as part of their policy to become carbon neutral by 2020. This research undertakes an innovative approach by undertaking a detailed examination of building adaptations in a global city; then it is possible to identify the nature and extent of typical levels of adaptation, as well as determining the relationship between different types of adaptation and building attributes.

This paper addresses the question: what is the relationship between building adaptation event, classified as ‘alterations and extensions’ in the CBD and building attributes? Using the Melbourne CBD as a case study this research analysed 5,290 commercial building adaptation events and the relationship with specific building characteristics from 1998 to 2008. The inclusion of all adaptation events that occurred during this period ensure this research is the most extensive and comprehensive analysis of this level of building adaptation undertaken in Australia. The outcomes of this research is applicable on a global basis and relevant to urban centres where existing commercial buildings can become part of the solution to mitigate the impact climate change and enhance the city.
Introduction
Arguably buildings contribute around half of all greenhouse gas emissions; Australian offices alone account for approximately 12% of all greenhouse gas emissions. As government authorities seek ways of reducing the contribution of cities to climate change and global warming, building adaptation appears to offer the only realistic means of reducing building related emissions by 38%. The 1,200 building program developed by the City of Melbourne aims to adapt or retrofit 1,200 CBD properties before 2020 with sustainability measures as part of their policy to become carbon neutral by 2020. Through an examination of building adaptations in the CBD it is possible to identify the nature and extent of typical levels of adaptation, as well as determining the relationship between different types of adaptation and building attributes. Accordingly this paper addresses the research question: What is the nature of the relationships between (a) building adaptation events in the CBD classified as ‘alterations and extensions’ and (b) building attributes?

Factors influencing building adaptation
For the purposes of this research the definition of adaptation 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” (Douglas 2006). Previous research identified and grouped factors under categories of economic, social, environmental, technological, legal and physical (Wilkinson et al. 2009). To sum up key factors for example, Ball (2002) found the local economy contributes to adaptation, along with building attributes such as age, physical condition, heritage value, size (i.e. smaller buildings were more marketable) and user demand (Fianchini 2007). An earlier study concluded building quality and character were determinants of successful adaptation.
A later study found accessibility to be a critical success factor, along with layout and flexibility for a range of differing uses (Fianchini 2007), whilst Barras (1996) found a relationship between age and obsolescence in London offices.

Physical attributes impact on adaptation potential and should be considered in decision-making. Gann and Barlow (1996) showed the technical issues in adapting offices 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. car parking, orientation, external noise and external access), size (e.g. 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).

Location is an important criterion for adaptation, with older buildings occupying prime locations (Ball 1999, 2002). Ellison and Sayce (2007) noted that within the paradigm of sustainability, location can be interpreted as accessibility to the building’s user group and transport nodes such as rail and bus transport systems add to the desirability of a property for adaptation. Table 1 summarises building adaptation attributes identified in previous research.

<table>
<thead>
<tr>
<th>Adaptive reuse criteria for existing buildings</th>
<th>Relevant study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>(Barras and Clark 1996; Ball 2002) Ball, 2002; Fianchini 2007.</td>
</tr>
<tr>
<td>Condition</td>
<td>Boyd et al. 1993; Isaacs (in Baird et al.) 1996; Swallow 1997; Snyder 2005; (Kersting 2006)</td>
</tr>
<tr>
<td>Height</td>
<td>Gann &amp; Barlow 1996.</td>
</tr>
<tr>
<td>Envelope and cladding</td>
<td>Gann &amp; Barlow 1996.</td>
</tr>
</tbody>
</table>
### Structure
Gann & Barlow 1996; Kersting 2006

### Building services

### Internal layout

### Flexibility (for 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)

### Heritage
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.

### Parking
Sayce & Ellison 2007.

### Character / aesthetics
Ball 1999.

### Acoustic separation
Gann & Barlow 1996.

### User demand
Ball 2002.

### Site conditions
Isaacs in Baird et al. 1996.

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**Research methodology**

Previous studies have examined the criteria for building adaptation, where researchers overwhelmingly adopted a case study approach based on in-depth analysis of a limited number of cases (Austin 1988; 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 studies the adaptation criteria have been identified, however this research approach is fundamentally different from this point. The research was undertaken in two stages. Stage one examined adaptation criteria which formed the fields for the building attribute database, where stage two analysed the relationship between the adaption criteria and the adaptive reuse of the building.
For this research a building attribute database of commercial buildings in the Melbourne CBD was assembled and populated from numerous sources including the Cityscope database (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). Building adaptation events were extracted from building permits received by the Building Commission in Victoria. Empirical data was gathered by visual building surveys. The building attribute database included variables listed in table 2, which have been categorised as physical, social, legal, economic and environmental characteristics or attributes of adaptation. The risk of an unrepresentative sample was avoided through the adoption of a census approach. As this research examines all building adaptation events in the Melbourne CBD between 1998 and 2008, 13,222 building adaptations was contained in the database complied for the study.

A preliminary task was to define the geographic area for the study. This research sought to investigate activity in a well developed, mature commercial market. The central business district (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. The CBD area used in this research is the original grid laid out by a surveyor named ‘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).

**Principal Component Analysis (PCA).**

PCA is a reliable, 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). PCA condenses 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) and was used to reduce the dimensionality of office building attribute data relating to adaptation in the CBD between 1998 and 2008. The initial step is to enter all the variables into the PCA to produce a smaller number of components. The next decision is based on the actual number of factors to retain and this decision was based on the Kaiser criterion where
factors with eigenvalues exceeding 1.0 only are retained. The factors were rotated using an oblique ‘Oblim’ rotation method with a final result being a table of identifiable factors which includes the loadings of individual building attributes. The contribution of a building attribute variable to each factor could be; completely positive (+1.0), completely negative (-1.0) or somewhere between.

Assigning meaning to a PCA solution involves interpretation of the pattern of the factor loadings (Hair et al. 1995). After analyzing the loadings across the factors, the threshold cut off was set 0.6 as recommended by Tabachnick & Fidell (2001). After a list of individual factors had been assembled where each factor contained high loading building attribute variable suggested correct factor names could be assigned. This analysis examined all events classed as ‘alterations and extensions’ the most extensive level of adaptation in the study and coded as level 4 adaptations in the study. The initial analysis examined 5,290 building adaptation events between 1998 and 2008. Each individual event was analysed further and 13 separate attributes were identified for each event as follows:

1. Aesthetics
2. Vertical services
3. Parking
4. Street frontage (metres)
5. Historic listing
6. Number of storeys (height)
7. Age in years (2010 minus construction year)
8. Typical Floor Area
9. GFA
10. PCA grade
11. Site boundaries
12. Site access
13. Property location

The PCA produced a total of 13 separate factors (table 3) where only the first three were significant with eigenvalues exceeding 1.0. Overall these first three factors contributed approximately 74% of the variance.
### Table 3 Total Variance Explained PCA Level 4 adaptation events

<table>
<thead>
<tr>
<th>Factor No.</th>
<th>Eigenvalues</th>
<th>Extraction Sums of Squared Loadings</th>
<th>Extraction Sums of Squared Loadings</th>
<th>Rotation Sums of Squared Loadings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>% of Variance</td>
<td>Cumulative</td>
<td>Total</td>
</tr>
<tr>
<td>1</td>
<td>5.832</td>
<td>44.861</td>
<td>44.861</td>
<td>5.832</td>
</tr>
<tr>
<td>2</td>
<td>2.572</td>
<td>19.784</td>
<td>64.645</td>
<td>2.572</td>
</tr>
<tr>
<td>3</td>
<td>1.214</td>
<td>9.338</td>
<td>73.983</td>
<td>1.214</td>
</tr>
<tr>
<td>4</td>
<td>.858</td>
<td>6.597</td>
<td>80.580</td>
<td>.858</td>
</tr>
<tr>
<td>5</td>
<td>.761</td>
<td>5.851</td>
<td>86.430</td>
<td>.761</td>
</tr>
<tr>
<td>7</td>
<td>.387</td>
<td>2.973</td>
<td>94.124</td>
<td>.387</td>
</tr>
<tr>
<td>8</td>
<td>.290</td>
<td>2.233</td>
<td>96.357</td>
<td>.290</td>
</tr>
<tr>
<td>9</td>
<td>.255</td>
<td>1.958</td>
<td>98.316</td>
<td>.255</td>
</tr>
<tr>
<td>10</td>
<td>.118</td>
<td>.911</td>
<td>99.227</td>
<td>.118</td>
</tr>
<tr>
<td>11</td>
<td>.053</td>
<td>.405</td>
<td>99.632</td>
<td>.053</td>
</tr>
<tr>
<td>12</td>
<td>.042</td>
<td>.320</td>
<td>99.952</td>
<td>.042</td>
</tr>
<tr>
<td>13</td>
<td>.006</td>
<td>.048</td>
<td>100.000</td>
<td>.006</td>
</tr>
</tbody>
</table>

### Table 4 Factor loadings - ‘Alternations/Extensions’ (Level 4) events

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Physical Size (Factor 1)</th>
<th>Land (Factor 2)</th>
<th>Social (Factor 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Storeys</td>
<td>.958</td>
<td>.048</td>
<td>.050</td>
</tr>
<tr>
<td>GFA</td>
<td>.958</td>
<td>-.009</td>
<td>.037</td>
</tr>
<tr>
<td>PCA grade</td>
<td>-.822</td>
<td>.023</td>
<td>.115</td>
</tr>
<tr>
<td>Site boundaries</td>
<td>.775</td>
<td>.203</td>
<td>-.009</td>
</tr>
<tr>
<td>Typical Floor Area</td>
<td>.743</td>
<td>-.053</td>
<td>.061</td>
</tr>
<tr>
<td>Site access</td>
<td>.737</td>
<td>-.057</td>
<td>.297</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>-.203</td>
<td>-.144</td>
<td>.485</td>
</tr>
<tr>
<td>Parking</td>
<td>.427</td>
<td>-.005</td>
<td>.423</td>
</tr>
<tr>
<td>Street frontage (metres)</td>
<td>.225</td>
<td>.886</td>
<td>.015</td>
</tr>
<tr>
<td>Vertical services location</td>
<td>.041</td>
<td>.861</td>
<td>.030</td>
</tr>
<tr>
<td>Property location</td>
<td>-.625</td>
<td>.695</td>
<td>.125</td>
</tr>
<tr>
<td>Historic listing</td>
<td>-.177</td>
<td>.175</td>
<td>.823</td>
</tr>
<tr>
<td>Age in 2010</td>
<td>-.476</td>
<td>-.123</td>
<td>-.632</td>
</tr>
</tbody>
</table>
Results and discussion
This section interprets the analysis and discusses each factor and their aggregate contribution to understanding adaptive reuse of buildings. Level 4 adaptations were those involving the most extensive works, short of demolition and rebuilding, such as alterations and extensions. The highest number of events featured in this category, illustrating that building owners of all commercial office buildings are more likely to engage in this type of adaptation than any other during the period 1998 to 2008. That owners are prepared and do engage in this level of adaptation is indicative of a high level of confidence in the Melbourne CBD market; that is to say that level 4 adaptations will recoup the investment through higher rental yields, increased capital values and lower vacancy rates than if the building was either not altered at all or adapted to a lesser extent. The contribution of the individual attributes to each factor was then examined where each factor was allocated a name based on the loadings (table 4).

Table 5 Summary of PCA Factors ‘Alterations and extensions’ (Level 4)

<table>
<thead>
<tr>
<th>Factor number</th>
<th>Factor name</th>
<th>Factor variables</th>
</tr>
</thead>
</table>
| 1             | Physical / size | Height (number of stories)  
                      Gross Floor Area (GFA)  
                      PCA Grade  
                      Site boundaries  
                      Typical floor area  
                      Site access |
| 2             | Land         | Street frontage  
                      Vertical services location  
                      Property location |
| 3             | Social       | Historic listing  
                      Age  
                      Aesthetics |
Factor one: Physical size
The variables number of storeys, Gross Floor Area (GFA), PCA Grade, aesthetics, site boundaries and typical floor area and site access are strongly to very strongly loaded on factor one. These variables explain 44.86% of the original variance. Component 1 has six variables and three relate to the physical dimensions/size of the property in terms of floor area and height (i.e. physical attributes). Of the remaining variables, two relate to site boundaries; that the degree of attachment to other neighbouring buildings and site access; the number of access/entry/exit points to the building. It is possible to refer to these attributes as ‘physical - size’. The final variable ‘PCA Grade’ is strongly and negatively loaded and relates to building quality. With a loading of .427 Parking is too weak to be included in the final interpretation.

Factor two: Land
Three variables are loaded very strongly to strongly on component 2 being street frontage, vertical services location and location (table 4). The variables explain 19.78% of the variance. In this component the variables may be described as influenced by land/design factors. The street frontage or width of the land parcel and the location of the property relate to land attributes. The vertical services are a design attribute that influence the flexibility of the space plan to adapt to different configurations of the floor plate.

Factor three: Social
The variables historic listing and age are very strongly and moderately loaded on component 3 and explain 9.33% of the variance (table 4). The age variable is negatively loaded and this can be interpreted as buildings age they are more likely to be adapted. The variables can be described as social attributes. Aesthetics, which is weakly loaded on component three, relates to building appearance and indicates that buildings having a poor appearance; that is to say being outmoded or outdated are less likely to be adapted. It is included in this factor given the relationship to age and historic listing.
Conclusions

There are two primary findings from the PCA. Firstly the results reveal three defined and readily interpreted factors (table 4). Secondly the initial finding from this 'alterations and extensions' adaptations (level 4) analysis is that the PCA has correlated variables that previous studies identified as being separate and distinct (Blakstad 2001; Kucik 2004; Arge 2005) which indicates that the relationship between building adaptation and building attributes is more complex than previously considered. Specifically the PCA has confirmed the following:

- There are distinct levels of commercial office building adaptation in the Melbourne CBD ranging from minor to major works.
- Most adaptations are in the form of 'alterations and extensions’ adaptations (level 4), the most extensive type of adaptation prior to demolition works and reconstruction.
- Physical building and size attributes are the most important building characteristics in 'alterations and extensions’ adaptations (level 4).
- Building appearance or aesthetics is more important in level 4 adaptation than other types of adaptation.
- Building quality (PCA Grade) is an important attribute in 'alterations and extensions’ adaptations (level 4).
- The degree of attachment to other buildings (site boundaries) is an important variable in 'alterations and extensions’ adaptations (level 4).
- Floor area influences the amount of adaptation undertaken at level 4.
- The number of entry and exit points highly influences ‘alterations and extensions’ adaptations (level 4).
- To a lesser extent Building width is important and is associated with location of vertical services and property location.
- Building age is associated with historic listing in ‘alterations and extensions’ adaptations (level 4).
No other research has investigated such a large number of events in any geographical area, in effect providing a census analysis of all events which occurred during a decade of activity.

The research questions have been answered with a high degree of detail and discussion and the importance of a relatively small number of building attributes has been found to influence adaptation to a high degree, some 73.98% of adaptation is explained by twelve attributes. The most influential variables or building attributes affecting 'alterations and extensions' adaptations are; physical / size (height, Gross Floor Area, PCA Grade, site boundaries, typical floor area and site access), followed by land characteristics (street frontage, vertical services location and property location) and lastly by the social attributes (historic listing, age and aesthetics).

Another major finding is that attributes previously considered influential have been found to have limited influence on adaptation events in this study. These findings begin to place important parts of the adaptation jigsaw in place. Through the enhanced understanding of the pattern of commercial building adaptation, it is possible to strategically plan and target policy making to optimise efforts to deliver the 38% reductions in building related greenhouse gas emissions and the objectives of the 1200 buildings program.

References


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