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**Motivation &
Approach**

Chapter 1: Motivation and approach

1.1 Introduction

When I was an undergraduate I was trained using cases and later, as a practitioner, individual case-based interventions were the basis of my practice. Documentation of cases within practice was driven by both professional and legal duty of care demands in conjunction with employer expectations. It was only later that I saw that cases provided a means for capturing knowledge in context. Like navigation, where latitude and longitude provide the means to navigate in uncharted waters, case documentation provides a means for integrating and learning from individual case-based redesign episodes where assessment and interventions are naturally linked.

As a community-based occupational therapy practitioner, the majority of my daily practice required modification of physical environments to enable quality of life and community participation for people with impairments of function, stemming from genetics, trauma, the ageing process and environmental demands which exceeded their capacity. As a consequence, I was involved in the late 1980s with writing the assessment guidelines for the pilot of the high-level home modification program within NSW (Bridge, Dearden, El-Alam, Escribano, Gwyn & Lloyd, 1988; Barry, Bridge, Cherry, & Ernest, 1989). Since this time I have had an abiding and academic interest in how design either affords or disables individuals. More narrowly, my interest has centred on the manner in which redesign interventions, particularly within housing environments, impact human functional ability, prevent secondary disability, and reduce formal care demands.

Later while studying cognitive science in a Masters Program, I saw the potential of using computational systems as a potential tool to capture and support housing redesign reuse. Since the late 1970s the holy grail of ‘smart’ documentation management has been the development of more standardised computer assisted systems. The need for documentation standardisation stems from a natural desire to improve the quality and coherence of problem-action cycles, to improve data quality, outcomes management, assist with data entry, and to assist the synthesis of data to create new knowledge (Coiera, 2003). Searching for a means to better access, learn from and reuse redesign cases similarly motivates this research.

This thesis is a major cross-domain undertaking. It draws on and incorporates current theoretical understandings derived from the domains of design and redesign theory in addition to case-based reasoning, health informatics, web design, database design,

psychology, sociology, occupational therapy, accessibility (i.e. barrier free and universal design) and environmental gerontology theories.

1.2 The structure of this chapter

In this chapter the following structure is used as the thesis covers a number of domains. There are nine sections. First, sections three and four cover the terminology, motivation, background and significance of the research work. These are designed to establish the contributions of the thesis in relation to current practice and the need to improve redesign capacity. This thus includes some case scenarios to illustrate why redesign practitioners and redesign consumers might benefit from a case-based redesign reasoning approach.

Second, section five reviews existing tools available for home modification practice so that the computational solution outlined in this thesis is understood in the context of other research endeavours. Third, section six sets out the research methodology, which is a combination of action-based computational simulation, is presented. Fourth, section seven sets out the aim, objectives, goals, themes and scope of this thesis are laid out. Fifth, section eight sets out the structure and layout of this thesis as a whole. Lastly, section nine presents publications during candidature relating to the concepts and ideas discussed in this thesis.

1.3 Terminology used within the thesis

Throughout this thesis the words ‘redesign’ and ‘home modification’ are used, as are the terms ‘human ability’ and ‘ontology’. Understanding why these terms have been chosen will assist in both making sense of the thesis and its contributions. Thus, a discussion and clarification of these terms follows.

1.3.1 What exactly is redesign?

The use of the word *redesign* is deliberate because of its incorporation into and difference from design. Nevertheless, the prototype developed is part of the *HMMinfo clearinghouse*¹ and so deals in the domain of home modification and maintenance.

Unfortunately as can be seen in Table 1.1 there are a number of words in common use often used synonymously.

¹ The HMMinfo clearinghouse is a capacity building project funded in May 2002, by the NSW Department of Ageing, Disability and Home Care (DADHC) under the Home and Community Care (HACC) Program. It is a website designed to collate, disseminate and advance home modification knowledge.

Table 1.1: Overview of redesign synonyms

Terms	Definition
adaptation	<ul style="list-style-type: none"> • The act or process of adapting. • The state of being adapted. • Something, such as a device or mechanism, that is changed or changes so as to become suitable to a new or special application or situation. • A composition that has been recast into a new form.
adjustment	<ul style="list-style-type: none"> • The act of making suitable to an end or the condition of being made suitable to an end: accommodation, adaptation, and conformation. • The act of adjusting or the state of being adjusted. • A means of adjusting. • A modification, fluctuation, or correction. • The act of making suitable to an end or the condition of being made suitable to an end.
maintain	<ul style="list-style-type: none"> • To keep up or carry on; continue. • To keep in an existing state, preserve or retain etc. • To keep in a condition of good repair or efficiency.
modification	<ul style="list-style-type: none"> • The act of modifying or the condition of being modified. • A result of modifying. • A small alteration, adjustment, or limitation. • The process or result of making or becoming different: alteration, change, mutation, permutation, and variation.
reconstruct	<ul style="list-style-type: none"> • To construct again; rebuild. • To assemble or build again mentally; re-create: reconstructed the sequence of events from the evidence. • To cause to adopt a new attitude or outlook: a diehard traditionalist who could not be reconstructed.
remodel	<ul style="list-style-type: none"> • To make over in structure or style; reconstruct.
redesign	<ul style="list-style-type: none"> • To make a revision in the appearance or function of.
renovate	<ul style="list-style-type: none"> • To restore to an earlier condition, as by repairing or maintaining. • To impart new vigour to revive.

Note. All definitions were sourced from the American Heritage Dictionary, 2000.

While each of the terms outlined may be said to have nuances of semantic difference, all key terms from the table concern change either to a design process or to an artefact or design product. The terms *redesign*, *adaptation* and *modification* have in common that they are functionally driven. However *redesign* is very much broader than *modification*, which is the term most commonly associated with specific corrections associated with redesign of living spaces for persons with disability. *Adaptation*, like modification,

implies reuse of some parts, but adaptation is broader because it encompasses change not just to function but sometimes also concerns change to design process or reasoning. *Adaptation* has a unique meaning in *case-based reasoning* models where it always refers to the methods or process by which case content can be successfully reused to solve new design problems.

The terms *modification* or *adaptation* are the words most commonly used to refer to change made to a home in order to accommodate a particular set of human abilities. The domain of home modification practice specifically addresses health, disability and safety problems. However because requirements that maximise the full range of human abilities are poorly understood they are not easily generalisable. Consequently, current housing design models simplify design knowledge by standardising human ability based on notions of ‘normal’ ability, thus unintentionally excluding persons whose abilities are exceeded.

Renovation or *remodelling* more commonly refer to changes made to housing for purposes other than disability. Both renovation and remodelling, can be distinguished on the basis of scale (modifications are typically thought of as less extensive), and are undertaken for a different purpose. Remodelling is typically lifestyle or activity driven, i.e. adding on a rumpus room for growing children. Usage of the term modification, implicitly de-emphasises fashion, aesthetic or stylistic concerns that are inherent in the notion of remodelling. *Maintenance* is not associated with redesign as there is no functional revision. However without maintenance the expected outcomes from modification interventions fail over time, so maintenance is included in computational modelling as an extension of the home modification prototype. This facilitates browsing and reuse, but isolates maintenance knowledge from that dealing with functionally driven redesign (i.e. home modification).

1.3.2 What exactly is ability impairment?

The term *ability impairment* allows quantification of the full variance of human abilities. It is a less value-laden term than *disability*, which is defined as “something that hinders or incapacitates” (Houghton Mifflin Co, 2000). While disability is the term more typically used to describe people with activity limitations in the health professional literature, its use is restrictive and it separates those with ability variations from the general population. For this reason both terms will be used within this thesis.

Disability will be used when a sub-population statistic or narrowing is intended whilst the more inclusive term *ability impairment* will be used where a wider application is intended. The requirements imposed by disability, whilst having sufficient regularity to

remind and prompt, are rarely if ever replicable without redesign to address individual difference. Even if this were not so, change in design practice alone cannot address problems resulting from existing infrastructure.

Differences in human shapes and abilities, in combination with physical, social and cultural environments, mean that many, if not all, built environments require redesign or modification to meet users' activity needs over their lifespan.

1.4 Motivation for case-based redesign method research

In an obvious sense, case documentation is an abstraction of reality defined by education and convention. According to the field of health care informatics (the study of data capture and transfer in health sciences), case documentation provides a written record of the history, treatment, care and response of an individual while under the care of a health service. Documentation is a legal requirement as is secure and confidential storage of case-based information. However the structure and format of documentation varies from task to task and institution to institution (Coiera, 2003). This disparate, service or provider based information process makes integrating, reusing and learning from home modification episodes extremely difficult, if not impossible.

This lack of uniformity of documentation practice has inspired many efforts to improve upon the ways service providers document their encounters with clients. One of the most widely employed systems in health care is the Problem Oriented Medical Record (POMR) method. The POMR is a system for structuring a health record to improve uniformity; it is still in widespread international usage. The POMR system provides a means of standardising the input of interventions over time and makes the recall and location of relevant information easier (Weed, 1968; Weed, 1969). Within the POMR system, case-based episodes naturally link assessment and interventions.

Weed (1991) also pioneered electronic documentation capture in medicine. An electronic medical record (EMR) system is a tool for digitally communicating and storing individually related information within and between health care settings (Cohen & Shabo, 2001). However, the type and extent of the documentation depends on the nature of the organization's products and processes, the degree of formality of communication systems and the level of communication skills within the organization, and the organizational culture (Coiera, 2003).

Electronic records were developed to address the need to gather information that is currently scattered across many institutions and computers (i.e. word processors, paper based files and a multitude of achieving systems). Currently no electronic record system

has been designed or developed for the home modification sector and existing approaches fail to structure or standardise home modification interventions as these fall outside the acute care health based domain traditionally covered by EMR systems. Further Weed himself identified the problems associated with decoupling assessment and intervention and so went on to develop a computational tool called a Problem Knowledge Coupler (PKC). The idea behind the PKC was to combine data from individuals over time in order to expose patterns and to make selection of intervention more appropriate (Weed, 1991; Weed, 1994; Weed, 1997).

However despite the need for and promise inherent in a digital case-based system for home modification practice, one should be aware of the barriers to case-based digital system implementations more generally as discovered via EMR rollout. These barriers include the well-documented one of preserving individual's confidentiality (Rind, Kohane, Szlovitis, Safran, Church & Barnett, 1997). For instance, many service recipients feel that direct consent must be obtained for their information to be shared or used in any manner that does not directly benefit them (Hunter, 2003). Also the uptake of digital tools has been slower overall than hoped for, partly because there is a generation of practitioners who are accustomed to working with paper-based documentation and partly because the amount of time expended on digital records systems is often viewed as time consuming in a context where it is not financially reimbursable outside an individual service consultation (Dable & Callaban, 2002). Nevertheless, a number of researchers believe that digital data entry systems can be structured so that they can be made quick and easy enough for routine case-based use. (Rector, Nolan, Kay, 1991). Moreover, moving from paper-based documentation to digital systems is an ongoing and increasing reality (Keshavjee, Troyan, & Holbrook, 2000).

1.4.1 Why a case-based method for redesign problem solving?

A large part of design practice consists of reusing design experiences (Wassemann, 2004; Wognum, 1994; Zdrahal, Mullholland, Dominique & Hatala, 2002). Past design experiences or cases are reused because of time and cost efficiency gains and because it is the way humans naturally reason (Elstein, Shulman, & Spafka, 1978). Humans are constantly reusing information, but require a conceptual framework to evaluate relevance prior to reuse (Waks, 2001). Prior experience assists experts to select name keys that effectively retrieve similar cases from memory, but novices learn best by doing and having the experience of expectation failure (Schank, 1996). The ability to store and retrieve information in the form of extensive case libraries contributes to *crystallised intelligence* (i.e. experience accumulated over time) (Hayslip & Panek, 1993).

Case-based learning is essential when knowledge is understood only in context and is thus difficult to formulate into logical or mathematical principles that can be easily generalised (i.e. the knowledge can be thought of as ill-structured). For this reason, case-based teaching has become the norm within certain professions such as law, medicine, architecture and occupational therapy. Experiential or case-based problem solving is especially useful when the subject domain, professional area or field is poorly understood. Design and redesign are both poorly understood and ill-structured in the sense that problem specification is generally insufficient to guide the generation of effective problem representations. Furthermore, neither design nor redesign currently has any explicit computational rule-based models capable of guiding the problem solving process (Watson & Perera, 1997a).

Further, knowledge concerning human abilities in the context of particular residential environments derives from phenomena that are inherently complex and dynamically indivisible. There is no generalisable stock solution for the full range of individual, geographic and cultural phenomena that shape housing need, instead “good solutions must be interpreted in terms of their real context” (Harrison, & Parker, 1998, p. 273).

A redesign intervention, for instance, must be observed and described in its intact, undivided state regardless of the number of features involved. It has to be observed as a dynamic whole in the context of a slice in time. Utilising a case-based approach facilitates awareness of a case as a non-arbitrary objective functional or teleologically sound whole. This is particularly important in regard to home environments, as they contain a large number of features that are compositional in nature and whose character is as unique as the humans they house (Stark, 2001).

Further, past research efforts trying to make sense of this complexity have been confined to enumeration and quantification of existing environmental barriers. As Stark (2001) points out, this is fine for establishing change in performance but fails to shed light on individual support patterns, particularly those that include multiple strategies (architectural modification, assistive devices, and care support). For these patterns to be understood, a model that captures the entire case (i.e. redesign requirements, redesign interventions, assistive devices, care support etc.) is required. According to Duffy & Duffy (1996) useful learning can be defined as *acquisition* (the process of receiving new knowledge); *modification* (the process of altering existing knowledge) and *transformation* (the process of creating new knowledge from existing knowledge). Cases as previously discussed are a familiar and already available medium for capturing redesign episodes and so have the potential to assist redesign learning in this manner.

1.4.2 Why a home modifications focus?

Home Modification and Maintenance (HMM) housing redesign was the application domain selected for prototype testing. In other words the problem selected for online case-based development is the representation of data associated with the assessment of humans with ability impairment, their homes and the associated modifications and maintenance interventions made to improve individual activity performance by the reduction of identified environmental barriers. Housing modification was selected as a focus because of the large scope of requirements that have to be considered and the relative importance of the topic. For instance, issues associated with ageing well and better preventive services are listed as major Australian Commonwealth research priorities (Australian Research Council, 2004).

1.4.2.1 Impact on functional capacity

The built environment, and housing in particular, has a powerful impact on health, mobility, independence, autonomy and wellbeing² for older persons and those with disabilities (Burrige & Ormandy, 1993; Conway, 1995; Ineichen, 1993; Krieger & Higgins, 2002; Lowe, 2002; National Housing Federation, 1998; Smith & Alexander, 1997; Thomson, Petticrew, & Morrison, 2002; Wilkinson, 1999; Young & Mollins, 1996; Xaverius & Mathews, 2003). Figure 1.1 illustrates how environmental changes are understood to reduce the disability threshold. The grey longitudinal box with the dashed line illustrates how environmental redesign can act to either raise the disability threshold or lower it as functional capacity (human ability) changes over time.

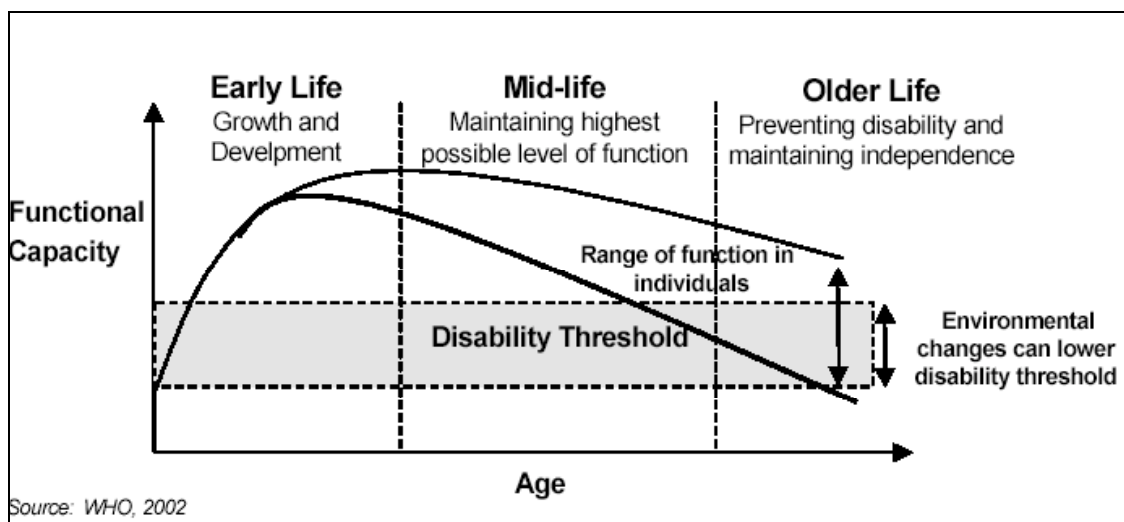


Figure 1.1: Maintaining functional capacity over the lifecourse (Straton et al., 2003, p. 20).

² Wellbeing is sometimes hyphenated and sometimes not, more recently it is understood as one word (see glossary of terms for more).

The fact that natural and man-made environments directly impact on human ability appears self-evident. Nevertheless this vital connection has often been overlooked. Thus the creation of more supportive housing environments is critical (World Health Organisation, 1997). Ageing correlates with impairments in ability, to the extent that at least one long-term condition was reported for almost all (99%) persons aged 75 years and over compared with less than a third (27%) of children aged less than 5 years (Australian Bureau of Statistics, 2002b). Figure 1.2 illustrates the linear correlation between impairments and ageing. This is in a context where the proportion of people aged 65 years continues to increase (Australian Bureau of Statistics, 2002a). Recent projections indicate that by 2031, the population of people aged 65 years and over will reach 22% of the total population (Australian Bureau of Statistics, 2002c).

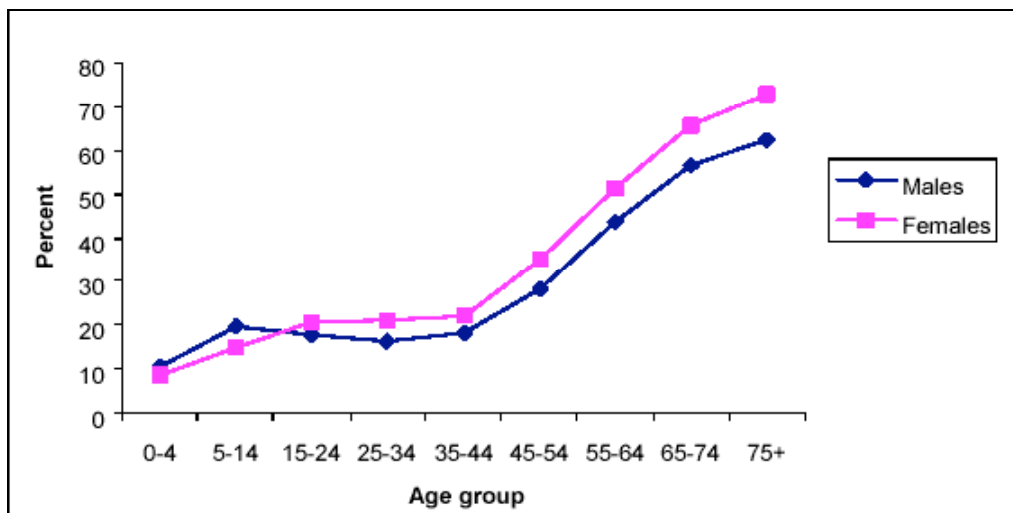


Figure 1.2: Persons reporting one or more chronic conditions, by age group, unpublished data from the ABS National Health Survey 2001 (Straton et al., 2003, p. 25)

Further, Australian census data indicates that the percentage of persons meeting disability thresholds rises from 4% for children under 4 years of age to 92% for those aged 90 years and over (Australian Bureau of Statistics, 2003). The sheer magnitude of demographic change brought about by population ageing in combination with the desire to age at home, makes rethinking current redesign practice critical. This is specially so when we also consider deinstitutionalisation, and the move towards more health care services being delivered into an individual home (Bridge et al., 2002a). These social and demographic factors mean more clients with multiple impairments are remaining in the community, in whatever housing stock is available to them.

1.4.2.2 Significant change in population and housing demographics

Significant demographic change is occurring in a context where governmental funding is limited but demand for HMM services are rising (AIHW, 2003). The numbers of

persons with ability impairments requiring HMM services in NSW continues to rise due to:

- ▶ greater societal expectations regarding the desirability of ageing within familiar environments;
- ▶ an increasing percentage of the population with brain injuries and dementia; and
- ▶ the process of deinstitutionalisation and loss of boarding house (licensed and unlicensed) beds.

This situation occurs within a housing market in which property prices are steadily increasing and where there is a shortage of metropolitan land. As a consequence, more efficient and effective housing interventions are critical (Harrison & Parker, 1998; Andrews, 2002).

Creating efficiencies within the home modification sector are an important part of this agenda in that they assist maximum independence and also act to prevent secondary disease and illness in the home, particularly for carers. Housing provides a viable long-term care resource (Stone, 2000). Housing is the ‘where’ in long-term care (Dalley, 1991; Kodner, 1996, 2003). This reconceptualisation of housing reflects recognition of the growing demands for more quality-of-life-enhancing and cost-effective alternatives to institutions (Regnier, 1994, 2002). For older persons and those with impairments of ability, the presence or absence of enabling housing makes the difference between continued community living or living in an institutionalisation (Brink, 1998; Pynoos 1992; Pynoos & Liebig, 1995; Pynoos, Tabbarah, Angelelli, & Demiere, 1998).

1.4.2.3 Relationship between home modification and home based care

However, home environments appear to have been neglected in efforts to develop better design tools (Oswald, Wahl, Martin, & Mollenkopf, 2003) despite the fact that interventions to assist in compensating for impairments have been advocated since the 1960s (Adkins & Mathews, 1999). Housing redesign for older persons and people with disabilities, such as ramps and handrails, allows a person to engage in major life activities (i.e. bathing, grooming, cooking, shopping etc.). This is particularly important when the amount of time spent within the home is considered (Hasselkus, 2002). For instance, disability generally results in more time spent within the home with Baltes, Mass, Wilms, Borchelt & Little (1999) finding that 80% of the activities of older persons typically take place there. Further, according to Oswald, Wahl, Martin, & Mollenkopf (2003), housing is not only an important part of everyday life but also directly correlates with proactivity and participation levels.

Redesign of existing homes to accommodate changes in human ability over the lifespan enables the occupants to live and remain in their homes as long as possible (Kendig, Bridge, Burkett, Gill, & Coiera, 2003). Maintenance and modification interventions can decrease accidents and injury with a reported seven-fold reduction in reported morbidity (Allen, 2000; Ambrose, 2001). Further, lack of access to appropriate redesign interventions may be both more expensive and traumatic especially if institutionalisation results (Harrison & Parker, 1998; Cumming et al., 1999; Mann, Ottenbacher, Fraas, Tomita, & Granger, 1999).

Housing designs, which include features such as stairs or other inaccessible building elements, impacts mortality and morbidity and places people with disabilities and their carers at risk of further injury (Public Health Association of Australia, 1993; Wylde, 1998). The World Health Organisation lists home related injuries fifth amongst the leading causes of death (Ranson, 1993). Home injuries in Australia, as in other countries, are a common occurrence. For instance, 12% of the Australian population indicated that they had sustained an injury in the previous month (Australian Bureau of Statistics, 2002b).

1.4.2.4 Escalating demand and the cost of not providing effective interventions

Fiscally, home injuries result in annual health related expenditure estimated at \$2,369 million for older persons (Hill et al., 2000), and \$660 million for children (Atech Group & Minter Ellison Consulting, 2001). Needless to say, injury is most commonly associated with housing that is of poor repair or quality (Ambrose, 1997; Dunn, 2002; Sandel & Zotter, 2000). Australian data indicate significant unmet home modification (35%) and maintenance (60%) needs (Bridge, Kendig, Quine, & Parsons, 2002a). Further, in an English study, the main reason cited for relocation was to eliminate the demands made by stairs (Buckle, 1971).

Although numerous design guidelines exist, little support is currently available for redesign and what exists tends to be over generalised, internally inconsistent and/or incomplete (Bridge et al, 1999). Further, as Stark (2001) makes clear, our understanding of the types of environmental modifications required within housing are still in their infancy. This in turn limits the ability of the HMM service sector to ensure best redesign practice outcomes. Inexperience and insufficient training amongst professional personnel including occupational therapists, builders and architects, compound the issues surrounding current design and redesign practice (Bridge & Martindale, 2002; Bridge & Flynn 2003).

Universal design is one response to this problem but one size can never fit all (Scotch, & Schriener, 1997). Additionally, treating disability as a single conceptual category is invalid because of huge individual variance in conjunction with classification difficulty (Dalley, 1991). American housing statistics cited by LaPlante, Hendershot and Moss (1992) indicate that less than 10% of the 100 million existing residential units have features that accommodate human ability impairments relating to assistive device use and reaching limitations. Additionally, the majority of new housing units do not contain features that facilitate accessibility, visibility and adaptability for individuals with ability impairments (Duncan, 1994). The absence of reasonable quantities of universally accessible homes means that home modifications will continue to occupy a unique position over the next century or more.

1.4.3 So how can an online case-based approach meet the needs of service providers?

The professionals involved in home modification provision are diverse and come from a variety of disciplines. They encompass coordinators, architects, occupational therapists and the construction sector tradespeople involved in making the modifications a reality plus their clients the individuals with impairments. In developing a useful computational tool, consideration must be given to ease of navigation and representation structures that support the majority of users, as it is the users' cultural background, personal experience and purpose that determine design reuse (Voss, 1997).

Some examples of typical redesign users and reuse contexts may be helpful in clarifying the representation and navigation needs. The following four scenarios illustrate users' representation and navigation needs across differing home modification contexts.

1.4.3.1 Scenario 1: Reuse assists redesign problem framing for students

Jane is on fieldwork placement and has just received a referral for a new client, Tony, a 38 years old who has sustained a severe head trauma. Tony is dependant on full physical assistance for all transfers but is independently mobile in an electric wheelchair. It is clear that Tony will probably require extensive bathroom redesign services prior to being discharged home. However, Jane has not previously seen a client with this diagnosis before. Although Jane works in a specialised head trauma unit, patient confidentiality legislation and medical record indexing prevent Jane from accessing prior case records to retrieve potential redesign solutions.

How might a case-based redesign system for people with disabilities assist Jane you might ask? Jane is still at the redesign problem framing stage and a tool that lets her browse and retrieve cases for clients with similar diagnoses and/or with small bathroom situations will assist her to sense the problems she may encounter in Tony's home when she conducts her first home visit. Client referral data is an important factor in how problems

are sensed and in deciding what aspects of incoming data to notice (Rogers & Holm, 1990a). Part of the problem solving process involves being able to form hypotheses very early on (Rogers & Holm, 1990b). Hypotheses are important in reminding us of prior case knowledge and are keys to selection and determination of useful protocols for data collection. The formation of hypotheses is thus important in shaping our future data inquiries and actions. Because of recalling similar cases, Jane will be reminded of constraints imposed by wheelchair circulation requirements, specialist equipment requirements and prior bathroom solutions. With this in mind, Jane will be better able to construct a mental plan of what to pay attention to while actually measuring environmental fit between Tony and his bathroom space.

It is assumed that the ‘best case’ is going to be a case that matches as many of the important variables in Tony’s situation as possible. This means that the problem ‘frame’ has to be wide enough to include basic referral data, details about the original bathroom components and any changes that were made resulting from the redesign process. Basic referral data may include attributes such as diagnosis, age etc. but more detailed assessment of client attributes includes height, assistive devices already prescribed etc.

1.4.3.2 Scenario 2: Reuse assists home modification coordinators learn and communicate with builders and subcontractors

Patricia is a home modification service coordinator and is looking for some well-documented redesign cases that she can use to learn about good and bad redesign practice. Patricia needs to find some cases where redesign does not comply with accessibility standards so she can facilitate discussion about how to apply accessibility standards to people’s homes with her subcontractors.

Patricia’s reuse needs differ in that she needs to retrieve cases against some specific reuse criterion. This implies an additional level of knowledge and means that a useful case memory should include information not just about problems experienced by consumers but also

individuated solutions used to resolve an individual needs in an existing home.

Information retrieved about interventions must contain sufficient dimensional detail that they can be matched against current accessibility criteria. Intervention case knowledge can then be used to illustrate what is or is not acceptable.

1.4.3.3 Scenario 3: Reuse assists occupational therapists to sense possible solutions for specific component problems

Paul a rural occupational therapist, and has just conducted a home assessment for an elderly lady with a fractured neck of femur. His client usually heats her bath water using a wood fired stove but cannot now manage the bending and wood splitting required.

Paul knows the bathroom is of a certain structural type, and has a certain size and shape. Additionally, Paul is looking for an alternative solution for heating bath water that

will minimise his client's disabilities. In this case, a case-based redesign reasoner needs to provide for methods to search for solution alternatives indexed according to solution components, as Paul needs to locate hot water systems most closely matching his clients bathroom configuration and service connections configurations.

1.4.3.4 Scenario 4: Reuse assists consumers to know what problems to look for and what potential solutions may work

Mary has cerebral palsy and is thinking of building a new home that will better suit her needs so she asks where she might find some pictures of bathroom modifications that might be suitable for her home.

Access to multimedia data will enable Mary to frame her needs and better communicate her redesign intent. Case-based redesign tools to aid communication between the designer

and a client are critical because design ideas and the use of past experience starts there (Harper, 1978, p 80). Retrieval of relevant graphics thus facilitates redesign goal setting and better redesign outcomes for Mary. In Mary's case, the user's perspective influences the way a problem might be formulated and may require inclusion of multimedia data such as images.

1.4.3.5 Implications of practitioners case-based usage needs

Accommodating experts and novices plus a variety of means of formulating problems requires a means of representing and indexing concretely a wide variety of redesign components and individual person related detail. As can be seen from the four scenario examples provided, the way the problem was 'framed' differed for each user. Framing is the process of selecting and naming an attribute or set of attributes that case retrieval needs to address (Kolodner, 1993, p 84). Successful computational application requires that the case contents contain relevant components parts and that the case-based system is sufficiently flexible to cope with a variety of users' needs. For instance, Jane's problem was framed primarily by the size of Tony's wheelchair and by the need to eliminate as many changes in level as possible to reduce additional manual handling. The fact that Tony was 38 years of age and had a diagnosis of traumatic head injury, although important in differentiating him from a child and/or someone with a degenerative disability, would not necessarily locate the most useful case. Thus locating a case that which has a wheelchair of the same type or a case where a step was eliminated or hoists employed are likely to be more helpful in this scenario.

1.4.4 What is the current Home Modification situation in NSW?

The Home Modification and Maintenance (HMM) sub-program is a national program designed to ensure residential dwellings enable functional independence of occupants

and safe care provision if required. The scheme delivers an important service to aged and/or disabled persons and their carers to enable them to remain at home. Moreover, in terms of governmental investment, the Home Modification and Maintenance services within NSW represent a significant slice of State/Commonwealth investment with governmental investment estimated to be in the order of \$50 million over the next few years (Bridge & Flynn, 2003). Funders typically place the highest priority on functional outcomes but failure to factor in meaning and personalisation can lead clients to reject interventions (Clemson, Cusick & Fozzard, 1999; Bridge, 1999). Consequently, any model developed has to be able to capture these factors in addition to the desired spatial changes to accommodate human ability limitations.

The HMM program specialises in helping the frail aged, older people, people with disabilities and their carers to remain safely and comfortably in their own home by providing home modification, maintenance and advice on building related matters. The HMM program plays a pivotal role for provision of other HACC services by providing a safe environment for care workers and by enabling the person with greater independence and so decreasing their care needs. The HMM program provides a range of one-off services to those within the target group including:

- ▶ minor dwelling repairs (i.e. replacing gutters, securing rugs and cords, fixing floors & decks etc.);
- ▶ home upkeep (i.e. painting and yard maintenance);
- ▶ minor modifications (i.e. provision and installation of grabrails, handrails, lever taps, non slip coatings and widening of doorways); and
- ▶ major modifications (i.e. internal/external ramps, redesign of bathrooms and kitchens and conversion of gardens to low maintenance).

There are currently very few specialised training programs for home modification practitioners, so learning by doing remains the norm for builders and those in the role of HMM coordinators, which raises particular problems for newcomers. Consequently, service providers value the sharing of cases as a means to improve practice outcomes, reduce workload and prevent costly mistakes (Bridge & Martindale, 2002). Access to cases can guide reasoning via comparison with prior solutions and by directing attention to salient case features. Thus a computational system that supports home modification practice should:

- ▶ enable the rapid collation and dissemination of a home modification cases;

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- ▶ provide a means of making rapid comparisons between cases based on similarity across housing, activity and client features;
 - ▶ expose new home modification practitioners to cases to promote understanding and retention;
 - ▶ reduce data entry and double inputting;
 - ▶ capture redesign variables when cases are linked by reuse (such as when an assessment leads to modification and maintenance interventions);
 - ▶ capture reuse patterns and regularities over time; and
 - ▶ be implementable on a personal computer, for access at home or work without additional cost.

Home Modification and Maintenance services and occupational therapists are generally familiar and comfortable with standard word-processing applications and the Internet (particularly electronic mail) based on in-depth interviews of approximately a third of the Home Modification and Maintenance services across NSW (i.e. 33 of the 109 services). The information needs analysis survey revealed that the majority of Home Modification and Maintenance services currently can and do access computers and the Web.

However some feedback indicated that some professionals believed that they had insufficient time available to use the Internet for problem directed searching and there was a minority who indicated that they had very limited knowledge of the Web, were unfamiliar with online searching and/or were not 'computer type people' (Bridge & Martindale, 2002). Given the unfamiliarity with computational tools amongst some professionals, it implies that any computational tool developed to address reuse and redesign learning must be developed to be as transparent and intuitive to use as possible. Further, it implies the emphasis should be on sharing and reuse rather than high-end computational decision support that may be perceived as threatening or off-putting to new or inexperienced online users.

1.4.5 Why an online computational implementation?

Today the Web dominates computational developments. The rapid growth of the Web has meant that we have entered a new information age (Zhong, Lui & Yao, 2003). The new paradigm builds from initial protocol development and standardisation to weaving the Web itself and presents a shift towards collaboration, interdisciplinary and multidisciplinary knowledge presentation, sharing and usage. Advances in Web

Technology are clearly viewed as the convergence of Information Technology (IT), Telecommunications and Data Networking Technologies (DNT) into a single online technology that has the potential to grow semantic knowledge or, as some like Antoniou and von Harmelen (2004) suggest, the creation of Web Intelligence (WI) as the next logical step.

According to the Australian Bureau of Statistics (2001) summary report on Internet usage, 56% of Australians have access to the Internet. This implies that while adoption has been rapid it is not yet a mass medium and gaps in uptake are still evident with a greater proportion of younger people online and with reduced ICT access clearly evident in smaller, poorer and less urban communities (Willis & Tranter, 2002). Nevertheless it is the only computational platform that enables multidisciplinary, cross platform access regardless of geographical location and at no cost to the user. Thus it makes possible a distributed and collaborative accumulation of redesign knowledge in the form of case-based experience.

These factors, in combination with experiential learning garnered from three earlier attempts lead to the decision to move to a dynamic Web implementation. All three earlier attempts were confined to bathroom design. The first attempt was undertaken very early in thesis candidature (1994-95). It attempted to apply a design prototype that grouped building elements into Structure, Behaviour and Function groupings (Gero, 1990). It relied on LISP programming to input cases (see Figure 1.3) to an existing case-based reasoning prototype known as Casekit (Balachandran, 1993). This attempt was abandoned for a number of reasons. First, it was abandoned because bundling human descriptions within spatial descriptions did not work. This is only possible if function can be ascertained *a priori* (i.e. it is a requirement of the original design). However, this assumes that all spaces have the same sets of activities and that these can be generalised. Unfortunately, even if this were possible, the transformation actions required in accommodating unanticipated human abilities in a redesign episode make its application problematic to the point that this approach becomes infeasible. Second, it did not make redesign learning possible. Last, the fact that each case to be entered required facility with LISP programming made it impracticable for implementation in the real world of home modification practice.

SUPERCASE: Mrs B
Frame: Subcase snippet - Toilet pan
Subcase description: "Standard 420 mm high, vitreous china toilet pan")
Relation: part-of bathroom case node
Function: enables
 (value (common hygienic-body-waste-elimination))
Behaviour: permits
 (value (common sewer-access))
Structure: overall-shape
 (value (common standard))
 overall-height
 (value (common 420))
 (units (common mm))
 overall-width
 (value (common 400))
 (units (common mm))
 overall-length
 (value (common 600))
 (units (common mm))
 location
 value (common wall-d)
 material
 (value (common vitreous-china))

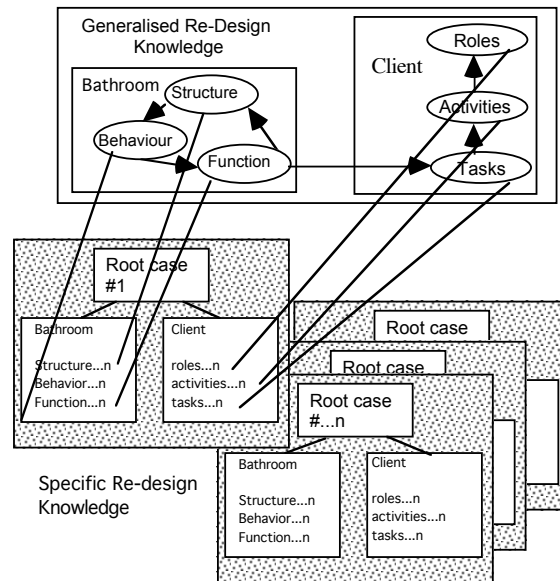


Figure 1.3: Lisp programming and case architecture for imputing bathroom redesign cases into the Casekit system.

As illustrated in Figure 1.4, the next experiment involved developing HyperCard stacks (1995-96). The selection of the HyperCard system was based on the fact that it supported multimedia and was more intuitive to use, and it had previously been used as an experimental decision aiding system platform for architectural design (Goel, Kolodner, Pearce, Billington, & Zimring, 1991). However, this also proved to have irresolvable limitations, it also required hard coding of cases by a person skilled in HyperCard programming and because it required users' to purchase the software which was only implementable on a Macintosh computer which is not generally available to home modification practitioners.

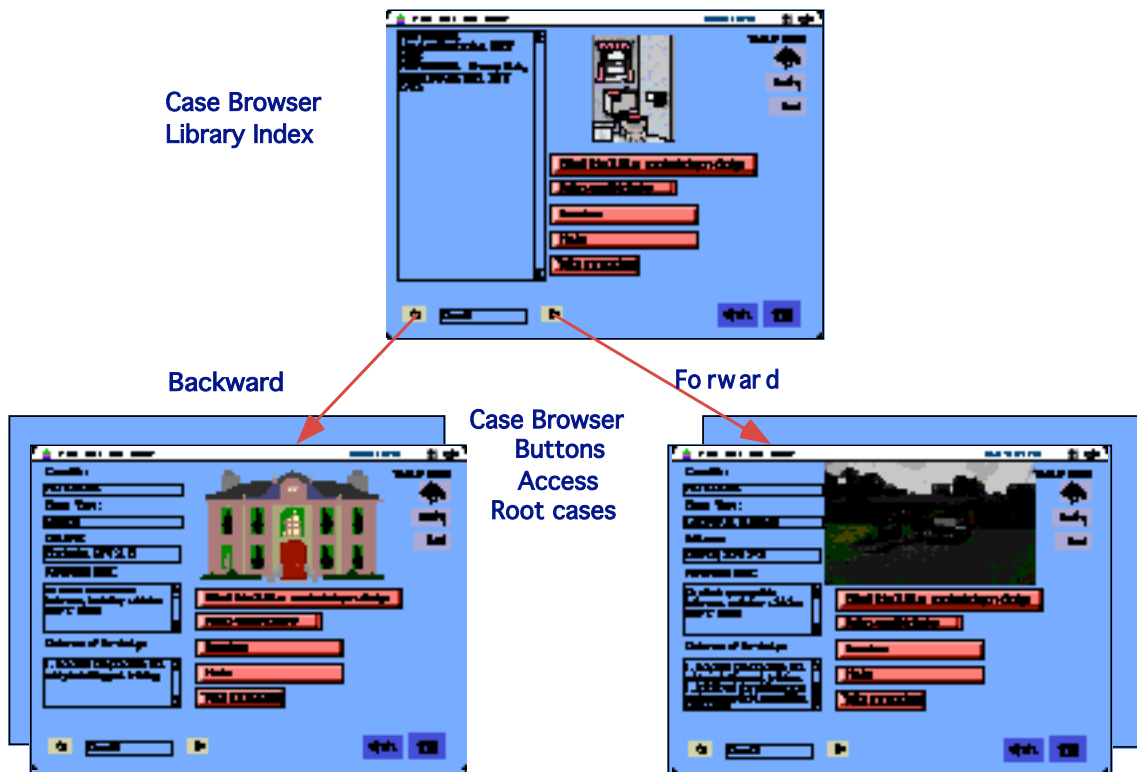


Figure 1.4: Bathroom browser implemented in HyperCard ver. 2.2

The third experimental attempt used static Web pages and hyperlinks (1998-99). The BRUSH prototype system was the result and this is illustrated in Figure 1.5. This attempt was also abandoned when Web developments made possible the more dynamic implementation via a database management system backend with the potential for practitioners to add their own cases online. The necessity of online case-acquisition by practitioners was a central motivation of this research endeavour as it is the only manner in which a case-library can become common property while building an online community (Kranich, 2004). Further it makes development over time possible while sidestepping the bottleneck of access to the full range of cases required.

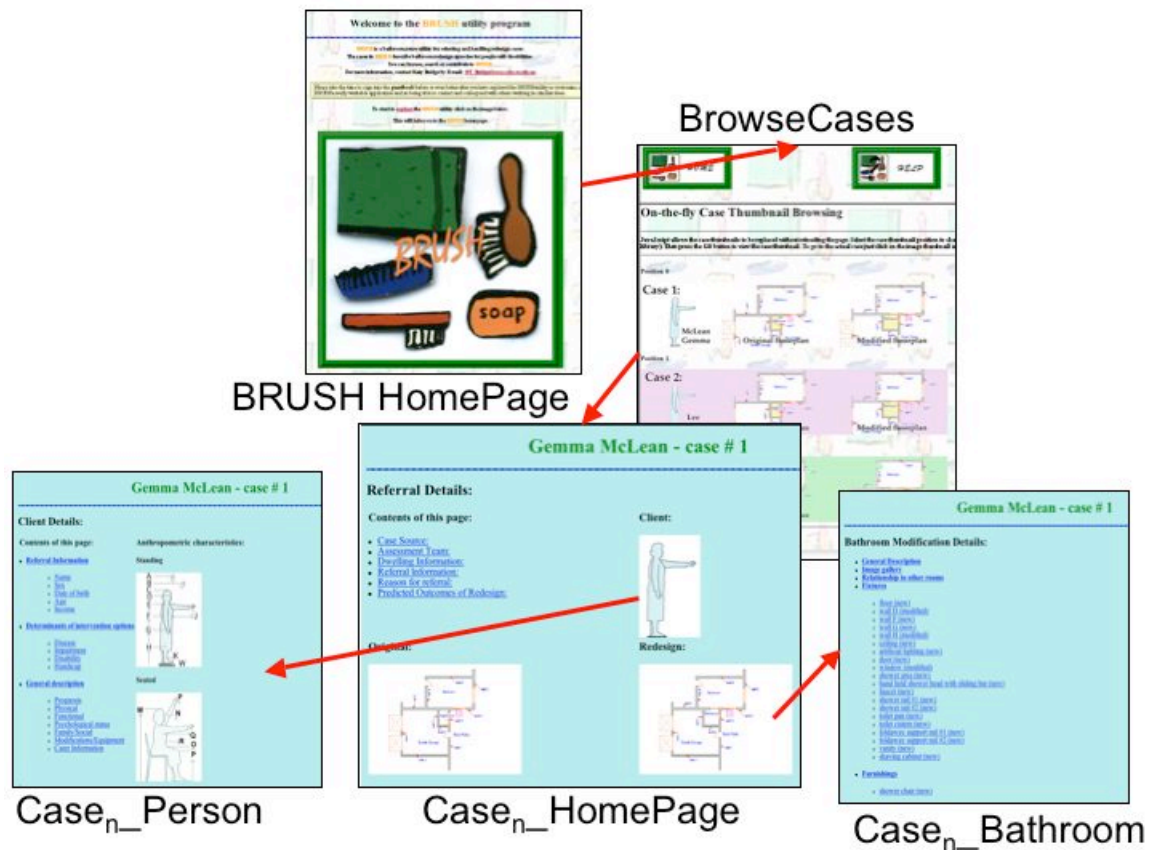


Figure 1.5: Architecture of BRUSH a static case-based Web experiment

1.5 What tools already exist for home modification practitioners?

Until now, redesign assessment and intervention have traditionally been researched separately. Assessment and intervention knowledge typically remains linked in individual case files held by individual practitioners. The separation of assessment and intervention research has resulted in a loss of redesign reasoning process knowledge. Previously, most formal effort has been expended on the development and standardisation of home assessment tools to assist practitioners to define and describe redesign problems. Table 1.2 overviews the four most researched and applied home problem sensing (assessment) tools which include the SAFER (Oliver, Blathwayt, Brackley, & Tamaki, 1993), Westmead Home Safety Inventory (Clemson, 1997; Clemson, Cumming, & Roland, 1996; Clemson, Fitzgerald, Heard, & Cumming, 1999; Clemson, Roland, & Cumming, 1992), HOMEFAST (Mackenzie, Byles, & Higginbotham, 2002) and the 'Home Enabler' (Iwarsson & Isacsson, 1993; Iwarsson, Isacsson, & Lanke, 1998; Iwarsson & Slaug, 2001). Of these four home assessment tools, the only one that involves a computational approach is the Home Enabler.

Table 1.2: Summary of standardised home assessment tools

Comparison	SAFER	Westmead Home Safety Inventory	HOMEFAST	Home Enabler
Stated purpose	Home assessment by occupational therapists.	Home hazard identification by occupational therapists.	Home hazard utility screening of older people.	Home accessibility assessment by occupational therapists, and as a social participation and planning tool.
Number of items	97 items in total.	56 items in total. Summary form also available for experienced practitioners.	25 items in total.	198 items in full version (also shorter version possible). Four parts, outdoor environment, entrances, indoor environment & communication.
Theoretical basis	Based on IADL categorisation (i.e. mobility, medication etc.) with inclusion of aspects of living situation (trip hazards) and fire hazards. Little or no theoretical base and associated issues with content and construct validity.	Limited to housing environmental data associated with falls and successful fall related interventions.	Includes data about function and environment. Little or no theoretical base and associated issues with content and construct validity.	Includes data about functional limitations and environment. Based on the enabler model developed from a 1979 review of the literature on accessibility.
Scoring	Paper based checklist with triparted scoring, addressed/not addressed and problem with space for comments. Total score may be summed and compared to 95 th and 99 th percentile data from Canada.	Paper based checklist with triparted scoring (i.e. hazard/no hazard and not relevant. Most are based on occupational therapist observation with client self report option being used for lighting alone.	Paper based checklist with primarily dichotomous scoring (i.e. yes/no). However, 13 items have a 'not applicable' option. Scores can be summed, fallers had a higher mean hazard score but this was non significant.	Computer application that creates functional and environmental profiles. Designed to run on a personal computer running windows. Primarily dichotomous scoring (i.e. yes/no). Computes weighted scores based on linking between functional and environmental profiles.
Characteristics of person and the environment identified	Evolved out of occupational therapy home visit proforma's currently in use in Canada. Concept of person and environment unclear.	Evolved out of international environmental review of fall factors, Concept of environment related to environmental settings. Concept of person unclear.	Evolved out of NSW Home falls safety checklist. Concept of person and environment unclear.	Evolved out of the enabler accessibility matrix and Swedish handicap codes. Concept of person similar to WHO impairment levels. Concept of environment related to environmental settings.
Interaction between person	Unclear, behaviours implicit with exception of cognitive impairment	Unclear, scoring is based on environmental hazards. The	Unclear, scoring is based on observation of a combination of	Relationships are predetermined and weighted according to observed

Comparison	SAFER	Westmead Home Safety Inventory	HOMEFAST	Home Enabler
and environment	markers such as wandering.	relationship to diagnosis, mobility, fall history and anthropometric dimensions implicit.	environmental factors and human performance in environment factors.	severity of impairment generally.
Relation to home redesign (modification)	Manual contains suggestions for interventions.	Free text space for problem summary and action plan.	Allows problem identification but no explicit link to redesign.	Problems are summarised across the four sections but no explicit link to redesign.
Strengths	Familiar and commonsensical. No prior training required if used by an occupational therapist. Logical layout. Problem identification linked directly to helpful hints about potential solutions. Evidence of psychometric review particularly in terms of reliability.	Excellent training tool. Comprehensive. Evidence of psychometric review (i.e. attention paid to issues of reliability and validity). Designed to be used in conjunction with the inventory prompt thus not bulky or difficult to apply.	No prior training required. Evidence of psychometric review of inter-rater reliability and content validity. Good reliability for showering and bathing. Evolved out of NSW Home falls safety checklist. Intended for rural application. Designed for speed of administration.	Having two separate profiles increases flexibility allowing one functional profile to be compared across several environmental profiles and vice versa. Evidence of psychometric review including content and external validity based on Swedish handicap codes. Inter-rater reliability good. Predictive environmental score is based on presence and severity of functional impairments.
Weaknesses	Limited information on sample sizes, selection methods and population demographics. No cautions or limitations listed. Summary score based on ordinal level data so meaningless. Insufficient space to record recommendations.	Takes considerable time to process manual and integrate concepts. Some aspects not always valid for the environment of concern. No detail provided about potential solutions. Insufficient space to record recommendations.	Reliability assessed with occupational therapists, occupational therapy assistants and a social worker. Significant reliability difference with expertise. Poor reliability for outdoor paths.	Does not address hazards per se (i.e. omits smoke detectors and fire egress). Requires education and training to apply appropriately. Consensus about functional limitations and degree of dependency on equipment unstable.

Note: The synthesis of material presented in this table stems from independent analyses of the assessment tools and their accompanying manuals and any published journal articles pertaining to them. Some of this analysis has been previously published as part of activity reflection feedback for the subject “Environmental Measurement: A handbook” (adapted from Bridge, 1996)

1.5.1 Observation and documentation of redesign problems

To try and ensure common outcomes for individuals seeking redesign assistance, practitioners are encouraged to select and apply a range of standardised assessment tools or assessment *attention directing frameworks*. In other words they adopt a structured pre-defined script for observation and documentation. These frameworks facilitate need identification and assist practitioners to sift through data to identify key issues and to problem-solve in a more consistent way. Problem definitions are crucial to both human observations and computational descriptions. For instance, identification of *hazards* requires clarity about what a hazard is, and reflection on what might be considered hazardous under what circumstances etc. In this case, poor night lighting in pathways to toilets or difficulty responding to a telephone call is associated with falls in the elderly (Clemson, 1997). The point here is, that in order to measure a construct like *hazard* one has to be knowledgeable about what constitutes hazards and be able to clearly identify them in a uniform manner.

1.5.2 Reasoning in redesign problem solving

Assessment of redesign need is a knowledge dependent human judgement task. Error is introduced in relation to lack of specific knowledge and the amount of decision choice possible. For example, the reliability of a home assessment will be higher if each item is either 'yes' or 'no'. When a practitioner is required to categorise an observation into no problem, minor problem, major problem etc., the chance of error within a category will be increased. Awareness that high gloss ceramic glazed tiles can be very slippery is well known amongst home modification practitioners. But how much is too much? How much better are terracotta or slate tiles, concrete or vinyl floor finishes? How do these materials behave when wet/dry and how are they affected by maintenance, age and cleaning materials? Not surprisingly, without prior experience or evidence to draw on, this was an area where significant disagreements were noted (Clemson et al., 1992).

As can be seen in Table 1.2, the tools vary significantly in purpose, comprehensiveness of coverage and theoretical basis. Thus each tool has particular strengths and weaknesses. While standardised home assessment tools all provide forms that are clearly set out and of comparable time to use, there are some fundamental differences regarding the population being assessed, scoring type, features highlighted and stated purpose across the tools reviewed. The most significant variation being difference in stated purpose resulting in significantly different construct categories. The stated purpose determines which constructs are operationalised as items and/or are considered salient.

Consequently, these vary significantly between tools, as do the assumptions adopted regarding the assessors training, educational qualifications and prior relevant experience.

All home assessment tools work to direct an assessor's attention to salient problems via individual assessment items. Nevertheless, the theoretical basis of each tool determines the actual constructs and concepts included. For instance, the Westmead Home Safety Inventory measures only one construct 'home hazards' but the SAFER measures aspects of the person (cognition, communication and personal care), aspects of the environment (lighting, rugs etc.), community mobility and support networks within the one scale. The fact that multiple aspects are examined in the SAFER tool makes it considerably more complex and thus establishing the theoretical relationships between aspects is much more difficult. Without clear theoretical relationships, there can be no content or construct validity and a tool that lacks validity will not serve to indicate in any accurate way descriptive, evaluative, or predictive features essential to outcome.

The SAFER, the Westmead Home Safety Inventory and the HOMEFAST tools are primarily ordinal measures and consequently summation of ordinal scores, as is suggested within the SAFER tool protocol is problematic. The SAFER classes are ordered into only two points of a continuum (i.e. 'addressed' versus 'problem'). We know that *addressed* is better than *problem* but we do not know how far apart they are on the continuum. Neither do we know how far they are from absolute values at either end of the spectrum. Thus knowing that a person has a *problem* tells us nothing about how severe the problem is. Scores on an ordinal scale cannot be added or subtracted. It is therefore not appropriate to apply even basic statistics and it would be meaningless to rate clients on an item such as *access/entry/security* and then calculate an average for a group of clients. Nevertheless, this is what the SAFER authors intend.

The Home Enabler on the other hand, stands apart from the other three tools whose focus is hazard identification. The Home Enabler's focus and theoretical basis is on *accessibility* instead. In addition, it remains the only home assessment tool designed for computational application with the significant advantage of increased flexibility in conjunction with simplified scoring. Nevertheless, it has a number of limitations that make it inappropriate at this point for Case Based Reasoning (CBR) application. The most significant being that it fails to capture or relate assessment and problem identification findings to actual interventions outcomes for later reuse.

As the review indicates, a number of assessment tools do exist and are evolving. However, the lack of a clear metric for measuring persons and environments means that specifying the presence of person-environment congruence apart from either the

subjective appraisal of the individual or the behavioural and affective outcomes of specific combinations of the environment and individual factors remains out of reach (Moos & Lemke, 1996; Rousseau, Potvin, Dutil, & Falta, 2001). While this is a severe limitation for home assessment tools in terms of psychometric quality, it does not restrict a less metric driven method such as CBR.

1.5.3 The centrality of reasoning to redesign practice

Of equal importance to redesign knowledge in identification and problem solving regarding a particular individual's home modification need(s) is the reasoning abilities of redesign practitioners. In human modification or redesign reasoning generally two of the most crucial but difficult areas are *problem sensing* and *problem validation*. Figure 1.6 illustrates these two stages and indicates how they relate to redesign problems. As can be seen in the illustration, human ability and environmental enablement are central to reasoning about human impairment (disability). While problem sensing and problem validations are human reasoning processes used during case-based episodes.

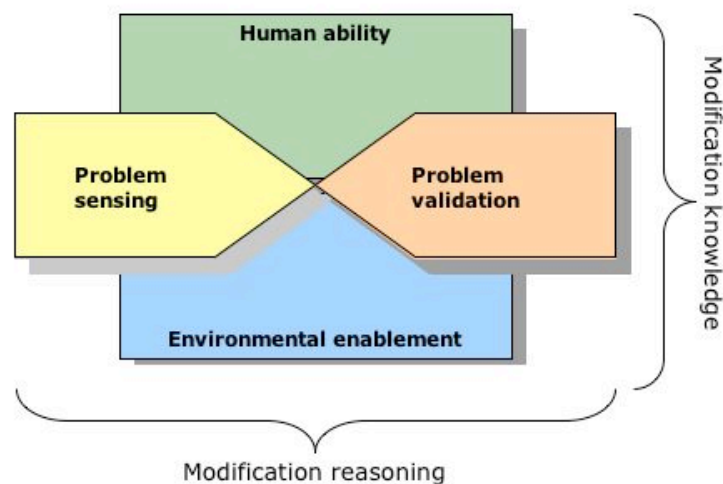


Figure 1.6: Modification reasoning showing both problem stages (adapted from Bridge, 1996, p. 21)

Both reasoning problem description terms relate to a practitioner's interactions and reflections on the data they observe. Both terms are interrelated and although presented in a linear form, in real everyday reasoning, follow so fast on each other that they are difficult to separate. Problem sensing is an active process that requires selective attention and assists human reasoners to make sense of complex and sometimes contradictory data. The development of the ability to *notice* and attend to *cues* appropriately in the home modification scenario is crucial in learning discrimination. Discrimination assists retrieval and browsing of similar useful cases.

In problem validation, or *intervening*, the focus shifts to the examination of discrepancies between the original mental image, and the real and gradually unfolding intervention scenario including what might work and how effective this might be. Problem validation requires overt action in extending and testing understanding. Observing and/or measuring humans and their physical environment in terms of features and component attributes provide the data needed for validating the hypotheses being formed.

The reasoning skills required of competent home modification practitioners are dependent on well developed critical and analytical reasoning abilities. The development of analytical reasoning skills as a means of improving decision-making is advocated by many sources (Barrows & Pickell, 1991; Fonteyn, 1995; Kassirer & Kopelman, 1991). Analytical skills are developed by provision of guidelines, home assessment tools and contextualisation using cases. Cases and assessment tools are not mutually exclusive and if compatible may in fact complement each other.

Reasoning approaches and definitions differ depending on context and discipline. Nevertheless, content-oriented approaches focus on knowledge but process-oriented approaches focus on task decomposition. Acquiring content knowledge presents challenges because the reasoner has to focus on what is salient and separate relevant data from background noise. Knowledge is the crucial factor here. Without knowledge, key data is overlooked, and irrelevant data is processed. What is noise and what is data, is of course, dependent on the ability to relate input to prior knowledge and to place the problem in context (Giarratano & Riley, 1989). In other words, data only becomes meaningful when it is transformed into information and then becomes knowledge. Identifying knowledge gaps and acquiring knowledge is the basis of adult learning and educational initiatives like problem-based learning (Boud, 1981; Dressel & Thompson, 1973). That learners experience difficulties with this is not surprising. For example, a study conducted by Ryan (1995) indicated that inexperienced therapists only extracted 27% of key data from the same medical charts as more experienced therapists.

Home assessment relies on trained observation and current practice is predominantly assessment by interview and observation, so why is it that skilled observation of the client and/or the environmental setting remain so problematic. Unfortunately, examination of person-environment fit is extremely complex, as many factors need to be noted, related and evaluated. For instance, when considering the location of a fitting as simple as a grabrail, an experienced occupational therapist typically considers at least 13

variables and their relationships to each other in order to assist a client to independently undertake a toilet transfer (see Table 1.3).

Table 1.3: Complexity of decisions associated with grabrail placement

Toilet grabrail attributes	Number and type of typical values to be considered	Relationship to client attributes
1. Length (end to end)	Minimum length is 300 mm and increments are usually in 150 mm units	Client height and heights of co-habitants, clients ability to flex and extend hips and knees and consistency of this ability
2. Profile	Circular, square, oval	Clients hand size, degree of muscle tone and dynamic grip strength
3. Diameter	Minimum is 20 mm can go up to 50 mm	Clients hand size, degree of muscle tone and dynamic grip strength
4. Shape	Straight, angled, curved	Number of clients utilising grabrail and their ability to shift centre of balance in normal sit to stand manoeuvre
5. Location of fixings	Wall, ceiling, floor	Clients upper limb segment length and preferred transfer procedure
6. Distance from pan to proximal projection point	Can vary widely	Clients arm segment length
7. Distance from floor to distal projection point	Can vary widely	Clients height and limb segment lengths
8. Material	Wood, plastic, galvanised iron, chrome, aluminium, brass	Clients ability to exert dynamic grasp, their torso and upper limb muscle strength and the possibility of contact with water
9. Fixings	Screws, loxins, dynabolt	Clients weight, wall fabric
10. Surface texture	Degree of slip resistance	Possibility of contact with water, excessive sweating in hands or contaminants such as soap
11. Angle of insertion	Vertical, horizontal, variety of angles in between	Number and height of clients utilising same rail, clients stated transfer method
12. Projection from wall surface	Can vary, minimum is considered to be 25 mm	Size of hand and chance of arm becoming entrapped should a slip occur
13. Obstructions and protrusions that might prevent usage	Pipes, wires, toilet roll holders	Ability to gain grip purchase

Note. The synthesis of material presented stems from independent analysis. It has been previously published as part of “Environmental Measurement: A handbook” (adapted from Bridge, 1996, p. 18).

Unfortunately, no matter how good observation or memory skills may be, humans are just not designed to cope with large amounts of complex data in a quantifiable fashion (Diffrient, Tilley, & Harman, 1981, p 43). Precisely because humans have difficulty in this area, the need exists for tools to assist a more comprehensive and accurate

measurement of variables. Skilled and/or trained observation is thus typically dependent on standardised tool application.

Most standardised assessments are simply purpose specific, attention-directing frameworks that assist in distinguishing regularities and are expressed in an understandable form (Harris, 1993). Unfortunately, while aiding human memory and assisting observations, these same attention-directing frameworks can also constrain practitioners in ways that limit their responses to a particular situation. It is the richness and depth of contextual information that truly conveys the necessary understanding and captures the relationships between assessments and intervention outcomes.

1.5.4 Towards a solution: Current computational initiatives

Knowing who will use the computational utility determines the vocabulary, viewpoints and redesign knowledge required. Redesign for people with disabilities is a professional specialty of occupational therapists and some architects. Unfortunately, redesign recommendations made are sometimes inappropriate especially for elderly persons where multiple disabilities, general frailty and mental impairments are often present (Faletti, 1984).

Computer technology such as CBR has the potential to improve redesign outcomes for all human users', including people with disabilities, by providing opportunities to present and interact with information in ways previously unseen. Redesigners, including Home Modification and Maintenance services (HMMS) and occupational therapists want to be able to access and share cases online as most cases are done privately and are thus currently inaccessible (Bridge & Martindale, 2002). This is particularly important as the majority are currently paper-based, and are lodged within physical document management systems where they can only be retrieved by staff currently working on the case. Home modification cases are therefore not available for general reuse or relearning purposes.

Because of the problems associated with making appropriate redesign recommendations, some attempts have been made to develop artificial intelligence, and knowledge-based system (KBS) tools that could be applied to the redesign area. Examples of which include the development of two rule-based expert systems, one aiming to supplement building knowledge required of occupational therapists redesigning existing houses for persons with disabilities (Morris & Fisher, 1987) and the other LIFEASE (Christenson, 1992) a commercially available tool that assists in the prescription of adaptive equipment.

Uncertainty and incompleteness of knowledge were major reasons why the KBS, designed to supplement building redesign, stalled (A. Morris, personal communication, March 24, 1994). A gap exists for technology to be developed that will better support redesign. The development of a case-based approach seems sensible because of difficulties associated with knowledge acquisition and the issues of contextualisation of knowledge-based problem solving experience with purely rule-based design systems (Maher, 1990).

1.5.5 Case-Based Reasoning

The development of the ability to notice and attend to cues appropriately in the redesign scenario is crucial in learning discrimination. CBR is a useful tool for intelligently supporting both experts and novices in finding satisfactory design and redesign solutions. Case-based recall provides the user with at least a starting point if not a complete or comprehensive solution (Watson & Perera, 1997a). However, exploration of issues related to structuring and representing redesign cases for reuse breaks new ground. A redesign case differs from a design case in that it needs to contain the modifications and transformation process in addition to the original design description. Development of a redesign model and suitable representation is important because a significant part of design practice is based on recycling or modifying existing artefacts to better accommodate new requirements. In addition, the ability to encode redesign cases makes redesign knowledge more explicit, accessible and transferable.

In addition, reference to prior case knowledge assists in identification of regularities and irregularities. For instance, Schank (1996) believes that active interaction with prior cases promotes human knowledge acquisition. The belief that human learning involves linking new problems to previous cases matches the current understanding of how students learn architectural design (Schön, 1991b). Thus CBR presents an attractive process model for storing and accessing knowledge in context (Maher, 1990). CBR in computational terms means developing encoding, matching and adaptation strategies to facilitate reuse (Riesbeck & Schank, 1989).

CBR research has led to the development of models and techniques suitable for structuring and representing existing designs so that they can be reused in new situations. Research currently focuses on determining parts that need to be adapted to satisfy new requirements, and on finding existing designs that can be reused in new design problems. Adaptation of a design involves transformation problem solving and this process is usually referred to as redesign. In reality, it is rare for a design to be reused in its entirety. Transformations are usually required to adapt the old knowledge to

the new context. Redesign is usually undertaken when an existing design fails to meet new demands in either novel or routine situations.

Nevertheless, a computational CBR approach suitable for dynamic Web implementation means developing an *ontology* suitable for redesign reasoning. The term *ontology*, in this sense, defines terms and term relationships to form a taxonomy of concepts capable of defining semantic interpretation of relevant knowledge (McGuinness, 2002). This means specification of a redesign conceptualisation suitable for computation. Development of a redesign reasoning ontology enables computational representation that can be shared (Gruber, 1993). An ontological approach underpins a computational problem solving and, if done well, can enhance service delivery, quality of life and autonomy for people with disabilities.

1.6 Research methodology

Internet research requires a set of assumptions relating to ontology and methodological approach that differs from traditional research assumptions (Sudweeks, 2005). This is so for design of computational systems where the ‘action’ is in the design of the systems themselves and where pluralism and serendipity assist system designers to articulate their theoretical understandings in order to better braid research and practice together (Laurel, 2003).

1.6.1 Computation simulation and numerical methods

Computational methods in modelling theory are growing in use, but may not be familiar to all researchers concerned with housing and ageing. Conducting a computational experiment facilitates understanding in a manner different from traditional approaches, e.g. field studies, laboratory studies, etc. While traditional approaches continue to generate a wealth of data, our ability to understand and relate these observations remains limited. Computational simulation aids reasoning about complex real-world phenomena by facilitating the interpretation of data.

Unpacking theories in sufficient detail that they can be implemented in the form of a computational simulation requires a level of specification that typically eludes traditional paper-based development. Computational modelling employs mathematical laws, thus the principles of their operation are explicit. Benefits include more accurate communication of ideas and the potential to uncover gaps or inconsistencies.

In traditional numerical simulation the model itself becomes the subject of investigation. The process of computational simulation provides a tool for exploring the model and making comparisons between competing theories. Additionally, the development of

computational prototypes can lead to hypotheses that guide future experimental work. The process of modelling, generating hypotheses and testing these hypotheses, can lead to improvements in the model and thus more complete theories.

According to Gero & Maher (1997) *design computing* research has three key goals:

- ▶ to develop theories, models and methods of designing as a process;
- ▶ to use these theories, models and methods as the basis for the development of tools; and
- ▶ to use these theories, models and methods as the basis for teaching.

Further a theoretical design computing method is advocated as it produces computational models of design through the identification of a set of theories and the logical consequences of the models resulting. This approach to design computing research involves:

- ▶ specifying relevant theories;
- ▶ deriving logical consequences of the theories to form models; and
- ▶ mapping the models and their consequences onto a particular domain to derive new results.

Employing the computational method, known as ‘abstract prototyping’, provides further, methodological structure. Abstract prototyping was developed by Opiyo, Horváth & Vergeest (2000) to support pre-implementation testing of design support systems. The abstract prototyping method is a form of action-based inquiry designed to discover proactively theoretical issues in computational approaches. Thus it aims to address both the system development aspects (i.e. the model development, the way components are interrelated and the mechanics of the software organisation) in addition to testing functionality (i.e. how it behaves as practitioners use it).

Under this methodology, action-based evaluations are performed at a number of levels of abstraction progressively as the new system evolves. This process is illustrated in Figure 1.7, which illustrates the five levels of abstraction in the development of new software. First, the theoretical models; second, the methodological underpinnings; third, the algorithms or computational formalism; fourth, the pilot implementation; and fifth, the system implementation. According to Opiyo, Horváth & Vergeest (2000) the real advantage is that application of this action-based methodology brings together

evaluative feedback in a more systematic manner from system developers in addition to just the end users.

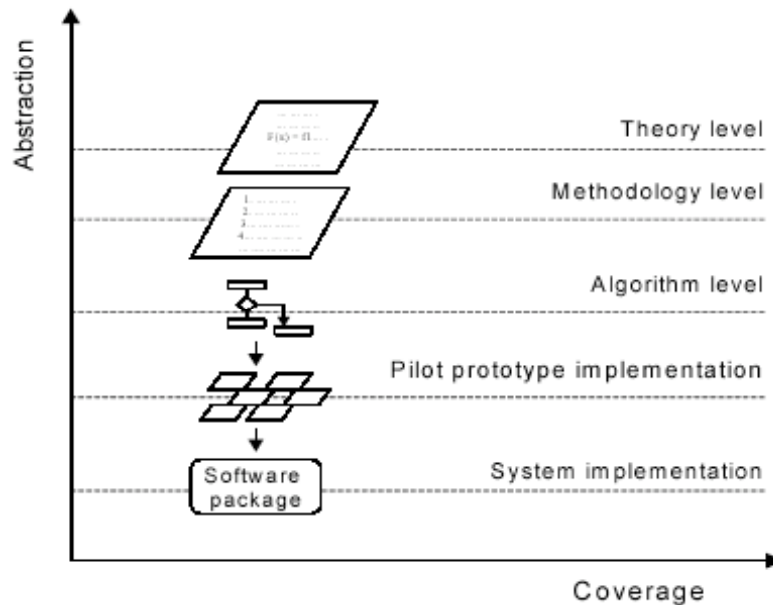


Figure 1.7: Abstract prototyping methodology for development of user-friendly software (Opiyo, Horváth & Vergeest, 2000, p. 3)

1.6.2 Action-based inquiry based on case-based reasoning and computational simulation

According to Morton Cooper (2000), action research is a method which links practice and the analysis of practice into a continuously developing sequence. Further, action-based inquiry results in some practical outcome related to the lives or work of practitioners (Stringer, 1996). While opinions regarding the theoretical background to action-based inquiry differ (Newman, 2000; Reason, 2001), nevertheless, all theoretical perspectives have in common the notion that empirical and reflective methods are in an action-based reflection cycle to address real world problems and result in some practical outcome related to the lives or work of the participants.

Action-based inquiry involves defining, exploring content, and analysing components with the intent of developing intervention strategies for real world problem resolution. The action-based process of inquiry also involves hypothesizing, theorizing and intervention, but it is the process of reflection on action that distinguishes action-research from other inquiry driven research (Stringer, 1996). Action-based research methods, typically include data obtained from self-reflexive inquiry and participant based inquiry (Moyer, 1999). Participant based inquiry is typically that gathered from qualitative and quantitative data documented in various ways i.e. in-depth interview, usability trials, usage statistics etc.

In line with these premises, the development of a computational solution to Home Modification and Maintenance case reuse had as its aim the development of a reflexive analysis about redesign problems which, on a group and individual level, the home modification practitioners experience during their daily work in the context in which they operate. This implies taking into consideration the totality of knowledge, skills, theoretical frameworks and methodological instruments needed to carry out the task, and suggests the use of both reflexive and participant data, both positive and negative, as the base material for analysis and evaluation.

In an action-based sense the application of a case-based computational simulation to a real-world home modification domain problem involves the process of articulating and examining existing knowledge, suggesting new case-based computational practices and evaluating the results. Examination of existing knowledge as we have seen so far, raises the following set of action-based inquiry questions:

- ▶ What is the relationship between design and redesign of spaces?
- ▶ What contribution could case-based reasoning theory make to the redesign of spaces?
- ▶ How can case-based redesign reasoning be modelled?
- ▶ What aspects of humans with ability impairments (disability) are important for environmental redesign of spaces?
- ▶ What ontological model best captures and relates relevant features?
- ▶ What might a relational database management system specification look like?
and
- ▶ Can relevant components be accessed, reused and acquired online by home modification stakeholders?

This thesis attempts to provide answers to these questions and the aims, goals, scope and thesis structure are designed to further clarify them.

1.7 Aim, objectives, goals and scope

This thesis combines design, disability and CBR theories to develop a case-based redesign decision support model capable of capturing human, environment and activity knowledge to support home modification (redesign) for older people, people with disabilities and their carers. A computational case-based paradigm is applied to the redesign process and product model developed. It is then applied to home redesign for persons with disabilities.

1.7.1 Research aim

This thesis aims to apply an action-based research method to integrate human ability, design and case-based reasoning knowledge in order to develop an online case-based redesign system for reasoning about individual ability within particular spaces.

The major contributions to knowledge resulting from this research can be summarised as objectives of both academic and practical interest as follows.

1.7.2 Theoretical objectives

- ▶ Differentiation of design from redesign models.
- ▶ Development of a model for redesign problem solving.
- ▶ Development of an ontology for the representation of attributes relevant to home modification interventions.
- ▶ Demonstrating how a case-based redesign system can be implemented into a web-based environment.

1.7.3 Practical objectives

- ▶ Development of a practical method of making redesign knowledge reusable for home modification practitioners.
- ▶ Integrating the redesign model with a home modification ontology to achieve the online acquisition and reuse of home modification cases.
- ▶ Development of a prototype case-based redesign system for ‘HMMinfo casestudies’.

1.7.4 Goals

The overarching goals for the proposed case-based redesign reasoner are as follows:

Goal 1 - To relate the original (assessment) housing design features to the redesign (modification and maintenance) cases.

Subgoal 1 - To apply the case-based redesign-reasoning model to cases so that redesign learning and reuse knowledge can be acquired.

Goal 2 - To acquire and reuse human, activity and space features to create new cases.

Subgoal 2 - To use the Human-Activity-Space model features to represent individual redesign housing case episodes.

Goal 3 - To enable online browsing and case-acquisition.

Subgoal 3 - To apply the case-based redesign reasoning model and the Human-Activity-Space model to database management system design with a dynamic Web interface.

1.7.5 Scope

The following themes recur throughout the thesis and are periodically restated from different perspectives.

- ▶ Redesign reasoning is both knowledge and context dependent.
- ▶ Redesign can be differentiated from design. It has different representational requirements and knowledge components.
- ▶ Representation of a knowledge-intensive computational system for home modification requires housing design, housing redesign, human and activity descriptions.
- ▶ Representation of redesign decomposition knowledge requires an ontology to express the structure and characteristics of the components.
- ▶ A CBR methodology provides an appropriate problem-solving paradigm for redesign by facilitating case-based learning and enabling case-based reuse.
- ▶ Ease of use, online accessibility and incorporation of multimedia are critical to system functionality.

1.8 Thesis structure and research questions

The thesis is organised within a tri-theoretical framework. Chapters one and two differentiate redesign reasoning from design reasoning from a design theory perspective. Chapters three and four are about specifics for representation and indexing with a CBR theoretical perspective. Chapters five and six introduce issues related to person centred reasoning and draw on human and activity based theories. Chapters six, seven and eight revisit CBR for the implementation of a prototype. Chapter nine draws conclusions relevant to the ontology and theoretical models developed. 8 Figure 1.8 illustrates how the thesis chapter structure relates to the original thesis contributions in design, CBR and disability theory. As is evident, six of the nine chapters (i.e. white boxes with a bold outline) represent original contributions to the blocks of knowledge required for computational decision support to enable human ability for persons with disabilities.

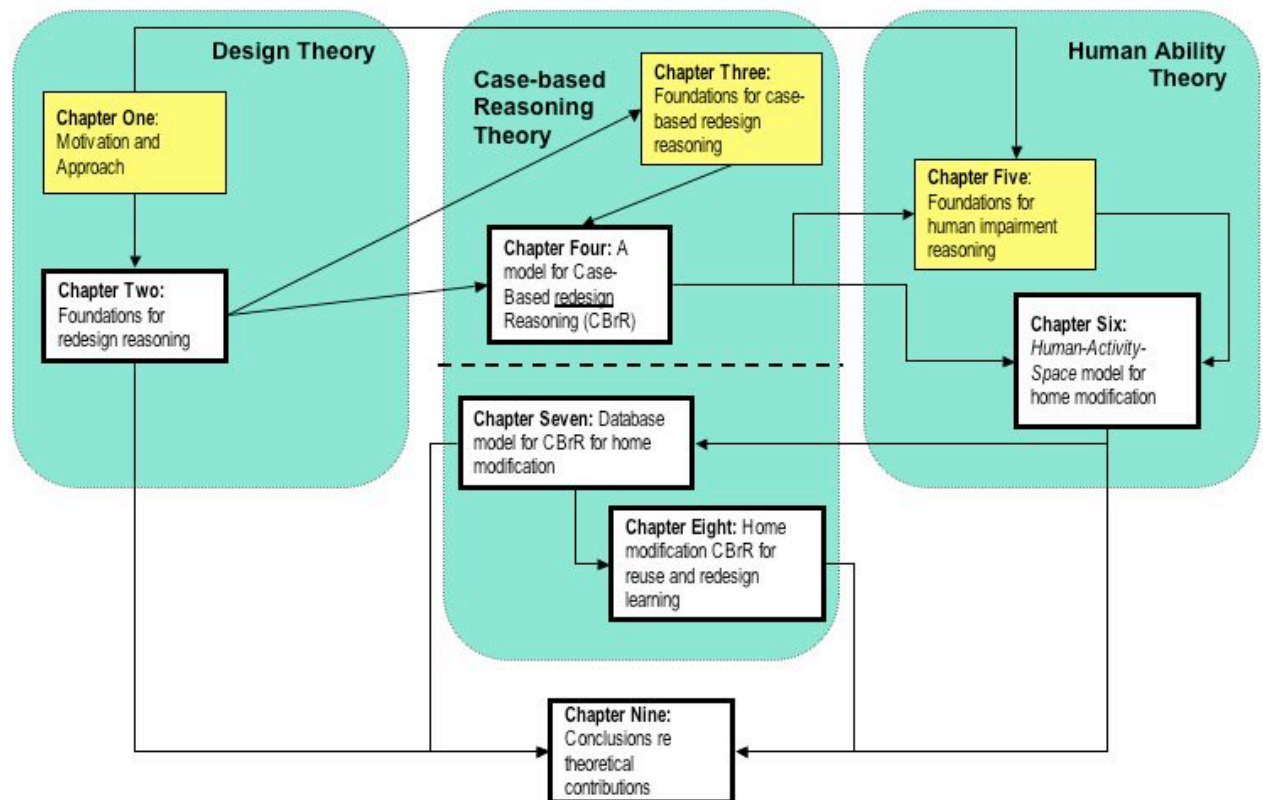


Figure 1.8: Overview of this thesis indicating the relationship between parts (bold rectangles cover original contributions)

The rest of this section describes each chapter in more detail.

Chapter two sets out to answer the question *what is the relationship between design and redesign of spaces?* in order to provide a theoretical foundation to the understanding of design and redesign process and products relevant to representation and reasoning. This is achieved by contrasting the current understanding of design with redesign. A concise review of both similarities and differences is presented to provide a contextual background to the redesign-reasoning model for people with ability impairments developed within this thesis. Design models are reviewed to establish the relevance of the research undertaken.

Chapter three sets out to answer the question *what contribution could case-based reasoning theory make to the redesign of spaces?* Thus this chapter reviews the foundations required for establishing and developing an ontology for case-based redesign reasoning. A concise review of case-based design processes, including case representation, case acquisition strategies, and case navigation, are presented to provide foundations for a redesign reasoning approach. A review of computational approaches to case-based design reasoning enables a global, external view and establishes some relevant similarities and differences to redesign.

Chapter four sets out to answer the question *how can case-based redesign reasoning be modeled?* It presents a general framework for the case-based redesign model developed within the thesis. The process of redesign representation is formalised and elaborated on and a theoretical basis for case acquisition, navigation, and reuse are articulated so that a relevant and novel computational ontology for a case-based redesign tool can be developed.

Chapter five sets out to answer the question *what aspects of humans with ability impairments (disabilities) is important for environmental redesign?* It reviews the foundations for disability reasoning. In redesign for people with disabilities, having an ontological framework for human responses becomes crucial, as the starting point for redesign stems from a perceived mismatch between the original design in its built form and the capacity of the human user. The review of human response modelling enables the development of an ontological model for human response suitable for a case-based redesign tool in terms of representation and navigation issues.

Chapter six sets out to answer the question *what ontological model best captures and relates Human-Activity-Space features?* It elucidates a case-based redesign-reasoning model capable of integrating representation of human response knowledge and redesign of the built environment. This chapter clarifies the problems and requirements a case-based redesign system for people with disabilities must address. Based on building representation, and human response representation issues of integration and navigation are addressed.

Chapter seven sets out to answer the question *what might a Human-Activity-Space relational database specification look like?* It applies the data model presented in chapter five to an online (or web-based), case acquisition, recall and adaptation process. This chapter overviews issues associated with hypermedia case representation and explores resultant issues in navigation and automated reasoning. Web specific design structures, case-acquisition and navigation structures relevant to a web-based implementation are described.

Chapter eight sets out to answer the question *can the Human-Activity-Space database management system model for redesign be usefully applied to home modification practice online?* It discusses the presentation functionality and usability of the *HMMInfo* case studies prototype. The prototype supports disability related housing redesign queries using the integrated approach outlined in previous chapters. The performance of the case studies prototype is evaluated in regard to its functionality in decision support for redesign tasks.

Chapter nine outlines the findings, contributions and conclusions of the thesis and possible further research directions.

Appendices provide descriptions of the database design, cases used to test the utility of the HMMInfo casestudy prototype and publications not available online that are directly related to the research undertaken in this thesis.

1.9 Publications related to the thesis

Earlier versions of some aspects of models and/or underpinning conceptual development have previously been published. All publications both directly and partially relevant are integrated within this thesis itself. All publications noted were developed during thesis candidature. Following is a list of these publications with a brief synopsis of content and description of how it relates to the thesis development. Publications listed as directly relevant are provided on the accompanying CD-Rom in PDF format for reference and clarification purposes.

1.9.1 Publications directly related to the thesis

The following five publications are directly related to concepts and materials raised within this thesis.

1. Bridge, C., Kendig, H., Quine, S., & Parsons, A. (2002). *Housing and care for younger and older adults with disabilities* (Final Report). Sydney: Australian Housing and Urban Research Institute (AHURI), The University of Sydney Research Centre. February 2002, [on-line] Available from <http://www.ahuri.edu.au/publish/page.cfm?contentID=30&projectid=39>

This research report supports the need for home medications and raises the high level of unmet need for home modification and maintenance interventions

2. Bridge, C. & Martindale, K. (2002) *Information needs of Home Modification and Maintenance Services in NSW*. Home Modification and Maintenance Information Clearinghouse. Sydney, University of Sydney. November 2002, [on-line] Available from http://plan1.arch.usyd.edu.au/hmm/hmm_web/resource_occ.cfm

This report supports the need for a facility that enables reuse and case-based learning. It establishes that home modification practitioners make use of past cases when developing interventions and points to the lack of any such facility at present.

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3. Bridge, C. & Simoff, S. (2000a). Computer-assisted Evaluation of Access to the Built Environment. In G. Moore, J. Hunt & L. Trevillion (Eds.), *Proceedings of PaPER '98; The 11th International conference on Behaviour and Physical Environment Research: A celebration of Environment-Behaviour research on the Pacific Rim* (pp. 353-363). Sydney, Australia: Faculty of Architecture, University of Sydney.

This conference proceeding paper presents the components and design decisions pertaining to the 'Accessible-Building' model. The *Accessible-Building* model provides the foundation for all spatial descriptions developed and presented in the Human-Activity-Space model developed and presented within this thesis.

4. Bridge, C. & Simoff, S. (2000b). Disability access to the built environment: On-line evaluation and information dissemination. In L. Eder (Ed.), *Managing Healthcare Information Systems with Web-Enabled Technologies*: (pp. 239-265) Idea Group Publications.

This chapter presents the *Accessible-Building* model's development and/original purpose. The *Accessible-Building* model provides the foundation for all spatial descriptions developed and presented in the *Human-Activity-Space* model developed and presented within this thesis.

5. Bridge, C. & Twible, R. (1997) Clinical reasoning: Informed decision making for practice. In C. Christiansen & C. Baum (Eds.). *Occupational Therapy Enabling Function and Wellbeing* (2nd Ed.). (pp. 158-179). Thorofare, New Jersey: SLACK Incorporated.

This chapter outlines the reasoning employed by occupational therapists in resolving human ability problems. It provides a background and case examples pertaining to assistive device and home modification intervention reasoning. Making clear that there are two stages; problem sensing and problem validation.

1.9.2 Publications partially related to the thesis

1. Bridge, C., & Kendig, H. (2005), Housing and older people: Environments, professionals and positive ageing, In V. Minichiello and I. Coulson (Eds.) *Contemporary Issues in Gerontology: Promoting Positive Aging*. N.Y: Allen & Unwin, pub. pp. 144-166.

This chapter discusses the problems associated with housing and the ageing process and the resulting unmet housing needs of older adults. It also discusses the necessity

for health providers to consider the current environmental context and individual meaning to the older person when reasoning about housing interventions.

2. Kendig, H., Bridge, C., Burkett, B., Gill, R., & Coiera, E. (2003). An Age-friendly Australia - the Built Environment. In J. Straton (Ed.), *Promoting Healthy Ageing in Australia*. Canberra: Prime Minister's Science, Engineering and Innovation Council. pp. 48-54

This chapter outlines the need for better housing design and greater understanding of the human abilities and impairments especially the lack of anthropometric data on which to base housing design decisions.

3. Bridge, C., Kendig, H., Quine, S., & Pepper, K. (2002). Disability and inability to obtain or maintain a home. *Parity*, 15(10), pp. 27-28

This journal article discusses how disability makes locating, modifying and maintaining a home difficult for younger and older adults. It discusses the need for more home modification and maintenance services to enable adults with ability impairments to age in place.

4. Bridge, C., Flatau, P., Whelan, S., Wood, G. & Yates J. (2003). *Housing Assistance and Non-Shelter Outcomes*. (Final Report). Sydney: Australian Housing and Urban Research Institute (AHURI), The University of Sydney Research Centre. June 2003, [on-line] Available <http://www.ahuri.edu.au/publish/page.cfm?contentID=30&projectid=82>

This report discusses the non-shelter outcomes of housing provision. The chapter on housing and health in particular indicates the many dimensions of housing design linked to poor health outcomes.

5. Bridge, C. (2003) *Basic biomechanical principles underpinning grabrail prescription for sit-to-stand transfers* (Occasional paper) Sydney: Home Modification and Maintenance Information Clearinghouse, University of Sydney June 2003, [on-line] Available http://plan1.arch.usyd.edu.au/hmm/hmm_web/resource_occ.cfm

This paper sets out the assumptions and principles associated with understanding the activity of transferring as it relates to grabrail prescription a home modification intervention.

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6. Bridge, C., James C, Kerley, P., Hovey, B., Bringolf, J., Hodgson, S. et. al. (1999). *Accessible Design in Australia: A National Approach for an Integrated Future - A Discussion Paper*.

This report discusses the problems posed by the plethora of design guides, which do not have a basis in research. It highlights the lack of evidence-based research to support building construction that includes the full range of human ability.

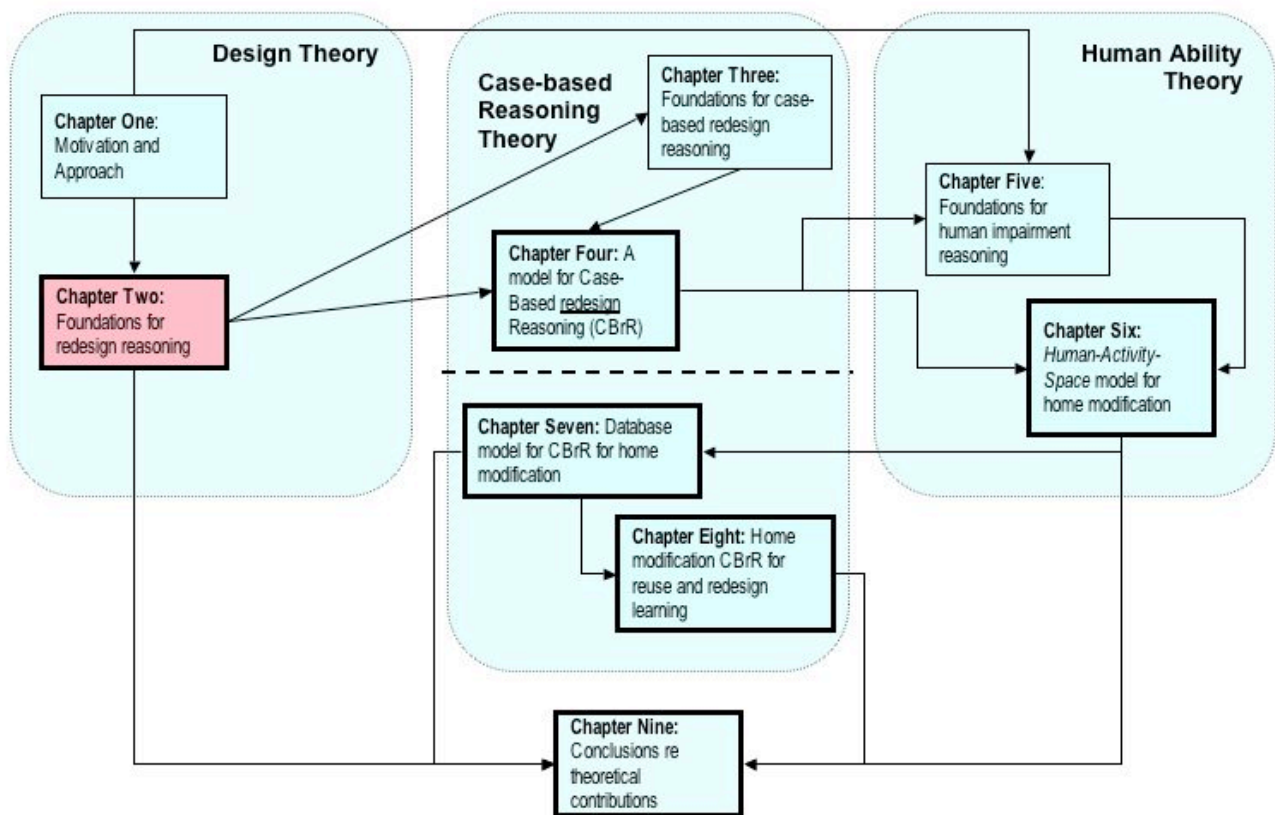
7. Bridge, C. (1999) *Communication with clients, architects, builders and tradesmen*. A handbook for the subject OCCP 5054 (15491). University of Sydney, School of Occupation and Leisure Sciences, Faculty of Health Sciences, Cumberland campus, Lidcombe, Australia.

This learning support package reviews the viewpoints of various stakeholders involved in home modification interventions. It highlights the variation in language and expectations based on a single domain orientation. It suggests some communication strategies to improve outcomes.

8. Bridge, C. (1996) *Environmental Measurement*. A handbook for the subject OCCP 5051 (15488x). University of Sydney, School of Occupation and Leisure Sciences, Faculty of Health Sciences, Cumberland campus, Lidcombe, Australia.

This learning support package reviews tools and techniques used to measure and quantify humans and the built environment that they perform activities within. It highlights the needs to obtain reliable, valid and accurate measurements of anthropometrics and spaces. It suggests some reasoning strategies and frameworks for integrating this information

2



Foundations for redesign reasoning

Chapter 2: Foundations for redesign reasoning

2.1 Introduction

This chapter contrasts current understanding of design with redesign. A review of both similarities and differences is presented to provide a contextual background to the redesign-reasoning model for humans with ability impairments, which is developed later in this thesis. Design models are reviewed to establish the relevance of the research undertaken. Specifically this chapter attempts to answer the question: *what is the relationship between design and redesign of spaces?*

To try and answer this question, definitions, process, product and learning requirements relevant to design and redesign of spaces are explored. This exposition provides a framework for explicitly representing redesign knowledge and for extracting data to support redesign reasoning. Redesign is needed when an existing design fails to meet new demands in either novel or routine situations. In the redesign task, the goal is to modify an existing artefact so that it meets a different function. The redesign process changes an existing design description to satisfy new requirements not anticipated in the original design formulation.

2.2 The structure of this chapter

This chapter is structured to provide a theoretical foundation for understanding design and redesign process and products relevant to representation and reasoning. This is achieved by contrasting current understanding of design with redesign.

First, design as a concept, product, compositional system and process are explored with the aim of clarifying redesign differences in order to identify redesign knowledge and problem solving techniques that can and should be conceptually distinguished. Formal computational articulation of redesign principles requires a clear understanding of component relationships and process transformations.

Second, design models are reviewed to establish the foundation, relevance and/originality of the research undertaken. The discipline of design science has focused attention on developing more scientific and explicit models of design reasoning but very few researchers have included redesign or tried to model redesign reasoning. Consequently, part of the motivation for this thesis and chapter structure stems from a desire for a more scientific explanation of redesign.

Third, the exploration of the relationship between design and redesign provides the foundation for the formalisation of redesign products and highlights the need for additional explicit representation of redesign process knowledge *to support* redesign reasoning and redesign learning. Last, the redesign reasoning and representation differences enable the commencement of a description of redesign components suitable for the process of computation.

2.3 Design and design models

There is a duality in the understanding and definition of *design* because the word refers both to a *product* and a *process*. A common dictionary definition of design typically includes reference to the “general form or arrangement” and to the output in terms of a “drawing that shows how something is to be made” (Hawkins, 1988). This is a reference to the actual artefact or *product*. According to Waks (2001) a *product*, is something expressed in physical space, which contains a form or pattern. However, design is equally about the activity or process of artefact development. The methodologies that are traditionally posited for design are those derived from and concerned with design of new artefacts (Bradford & Childe, 2001). As will be shown, this methodological assumption fails for redesign.

Design is usually referred to in terms typically associated with a specific type of application domain. For example, *architecture* refers to the design of buildings, *mechanical engineering* to the design and construction of instruments (i.e. tools, equipment and machines), and *industrial design* to the design of industrial products (e.g., in terms of shape, texture and colour) (Langen, 2002, p 1). In this chapter, the discussion of design and redesign remains generalisable because design and redesign differences hold true across domains at high levels of generalisation. However, as this thesis progresses, the examples move from the general to the specific, i.e. from spoons and motorcars to housing for people with impairments of ability.

2.3.1 Design as a product

As Langen (2002) states, our everyday human reality today would be unthinkable without *artefacts*. Artefacts are physical (such as houses) or non-physical (such as computer software), and they are designed to meet particular goals or functional outcomes, such as providing shelter or enabling everyday activities (i.e. spoons, toothbrushes, hammers, cars etc.). In general, the purposeful creation of an artefact demands thought about the desired *function* and what *structure* or form the artefact must have in order for it to perform in the manner anticipated. A designer makes things. Sometimes the designer makes the final product; more often, the designer makes a

representation; a plan, program or image of an artefact to be constructed by others (Schön, 1991a). However, as Artman (2002) makes clear, this is overly simplistic for building construction design domains like architecture where there is a clear separation between requirement analysis (planning or problem sensing), design (representation of intervention) and construction (making of intervention).

If *designing* concerns analysis (problem sensing component), a conceptual component (representation) and a making component that involves applying the conceptual component, three distinct processes are involved. Further, the representation *describes* certain material properties such as form, while the artefact embodies them. The closer the artefact functions in accord with its original design intent; usually the more successful the artefact is judged to be. In other words we infer functional behaviour by reasoning about tangible outcomes or products (Dym, 1994). All artefacts have a finite set of functional capacities and therefore respond or behave in certain ways depending on the contextual situation.

Routine design is typically solution-based or product-based with context-driven design variation (Lawson, 1997). However many design problem representations can be thought of as *ill-structured* (Simon, 1973) or *wicked* (Churchman, 1967; Rittel & Webber, 1973) i.e. the initial requirement descriptions are typically inconsistent, ambiguous, imprecise, or incomplete. The *process* of design can thus be seen as either routine or explorative. Nevertheless both routine and explorative design require a consistent, unambiguous, precise, and complete *product* description along with an artefact or design solution that satisfies it (Smithers, Corne, & Ross, 1994).

Interaction with a physical artefact or final design product solution reveals physical properties that are tangible. In other words, they can be seen, felt, touched and experienced by users. However, the designer manipulates mental representations, not the artefact itself. This raises the question of what the similarities and differences might be between design and redesign artefact or product descriptions and how these should be represented so that a computer can read them.

Formalisations of product descriptions provide the basis for any reliable computational support system. In this sense, within this thesis, the term *formalism* refers to a model definition that represents a set of modelling concepts used to describe a particular conceptual model's domain-specific content (Ferber & Gutknecht, 2001). Constructing a formal model that represents abstractly domain-specific content provides the foundation for any computational development. The exploration of and formalisation of models for design and redesign product representation enables causal dependencies to become

apparent and evolution, change and output to be manipulated and communicated. Additionally, the formalisation of a computational model capable of describing patterns provides a reasoning framework for facilitating quality, while reducing development time and costs (Cooper, Dai, Deng, & Dong, 2003).

2.3.2 Design as a compositional system

Highlighting the difference between an artefact and its representation may seem obvious. But the fact that the more typical product of design is an abstract representation not a physical reality is significant because it implies that a fundamental difference exists between the artefactual reality and its representation (Akin, 1982). Akin goes on to say that abstractions either selectively extract from reality some properties or aggregate properties such that generalisation is possible. This is particularly important in the early stages of design where concepts rather than features are being manipulated.

The notion of abstraction and aggregation involves an underlying belief that design products can be understood as *compositions* (Wijngaards, 1999). Often design proceeds by distinguishing and manipulating components or features. In a compositional system, components and their compositional relations can define product or artefact knowledge. A simple artefact such as a spoon can be thought of as having two components, the bowl and the handle, which are joined together to create the artefact that we recognise and use as a spoon.

This compositional relationship is illustrated in Figure 2.1. Both components can be manipulated separately. Thus, the difference between a soup spoon and a table spoon is in the design and shape of the bowl. However, the difference between a table spoon and a cooking spoon or teaspoon is primarily about size.

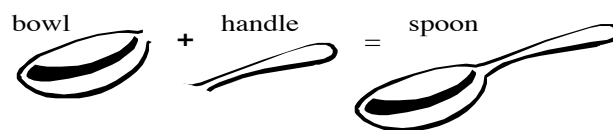


Figure 2.1: An example of a design artefact as a set of compositional features

If we continue with our spoon example, design as a compositional product description has both input and output features which reflect the difference between abstract and concrete knowledge. Design input for a new artefact or product is typically at a high abstraction level. However, output required for construction requires concrete knowledge. Input and output distinctions become evident as illustrated in

Table 2.1.

Table 2.1: Example of simplified diagrammatic representation of the product knowledge components needed when reasoning about design of a new spoon for toddler use

Design Input	Design Output
<i>New design brief</i> (i.e. new spoon = toddler_operation).	<i>Design problem label</i> (i.e. spoon = toddler_operation).
<i>Bowl design component composition knowledge</i> (i.e. understanding of spoon bowl relevant to design) <ul style="list-style-type: none"> ▶ shape ▶ fit_toddler_mouth ▶ material ▶ contain_semi_solids ▶ resist_bite_reflex 	<i>Bowl design component descriptions</i> (i.e. descriptions of spoon components relevant to design output: <ul style="list-style-type: none"> ▶ oval ▶ 30 mm ▶ stainless steel ▶ shallow curve ▶ 2 mm silicone coating
<i>Handle design component composition knowledge</i> (i.e. understanding of spoon handle relevant to design) <ul style="list-style-type: none"> ▶ shape ▶ size ▶ unbreakable ▶ slip_resistant ▶ diameter 	<i>Handle design component descriptions</i> (i.e. descriptions of handle components relevant to design output: <ul style="list-style-type: none"> ▶ cylindrical ▶ 80 mm ▶ PVC ▶ ribbed ▶ 17 mm

Compositionality in design (i.e. bowl, handle etc.) reflects an abstraction of artefact knowledge by *knowledge hiding*, which in turns reduces the cognitive load on the designer. However, both extraction and aggregation can result in loss of detail of artefact attributes. For instance, the plan and elevation drawings of a residential house, its plumbing and wiring diagrams, sketches etc., collectively constitute an abstract set of symbols, but the house itself does not.

Furthermore product representation of existing structures is quite different to design product representation. Different methods, conventions and techniques apply. In *measured drawing* or ‘as found’ drawings, representation of existing artefacts requires documentation consisting of rigorous measurements, photography, use of pre-existing drawings, assessment reports and disassembly (decomposition) of structures into their base components (Patterson, 1982; Chitham, 1980). Measured drawings, unlike design drawings, are created to document an existing artefact or complex structure (i.e. most typically buildings). Most of the conventions relating to this genre of drawing derive from architectural heritage, furniture redesign and engineering. Existing artefacts, unlike conceptual representations, are prone to wear and tear. Measured drawing aims to represent design artefacts accurately, including wearing, crumbling, sags and tilts not anticipated in the original design representation and documentation.

2.3.3 Design as a process

The objective of design process research involves mapping of design decision-making from the original formulation to its final solution effectively and efficiently. Thus process definitions describe the reasoning, which allows movements from a functional concept as a starting point to an end point that is an artefact (i.e. both real and virtual). The *process* of design as defined by Simon (1996) is the task of devising courses of action to change or create design products. In this sense, design is a goal-oriented problem solving process directed towards the construction of artefacts to attain particular functional goals. Design starts with an intended activity or use (Maher & Pu, 1997) and uses available knowledge to arrive at a description of an artefact that will produce those results (Gero, 1990).

Given that the starting point for design is conceptual, quite large paradigm shifts typically occur in how the problem is viewed as the design task is processed or reconceptualised. Because of the potential for the design product to substantially change or evolve during the design process, as previously mentioned some agreement exists that the *process* of designing commences as an abstract form of problem solving. The starting point for the activity of designing is thus problem formulation so other process phases can then be identified and formalised (Simon, 1973). Design formulations cannot be fully known *a priori* and must be clarified and specified as the design task progresses. Expressions of need or desire, while they may suggest a problem to be solved, are not explicit problem statements (Smithers, 1998).

The articulation and modelling of the design process by previous design researchers has been pursued to better clarify and communicate design methods or design tasks that the designer needs to perform in order to produce a design product. Many modellers of design processes are content to prescribe a design process (Dym, 1994; Jones, 1970). However other modellers seek to facilitate creativity in design by the application of formalisms for representing general problem solving processes (Maher, 1990). The approach to formalisation depends on the intended application or purpose of the model. In this thesis, the purpose is not to discuss or present all the ways the design process has been dealt with in the literature, but to present a generally accepted formalism that will assist the reader to appreciate the differences between design and redesign as process activities.

The most generally accepted design process model involves a basic decomposition into phases (Asimow, 1962). These are generally described within the design community as formulation, synthesis and evaluation (Lawson, 1997; Maher et al., 1995; Gero, 2000).

As Figure 2.2 illustrates, there is an implied order between phases and evolution of the design product is dependent on movement between the three phases. The three phases represent particular functions that require different types of knowledge and use different reasoning.

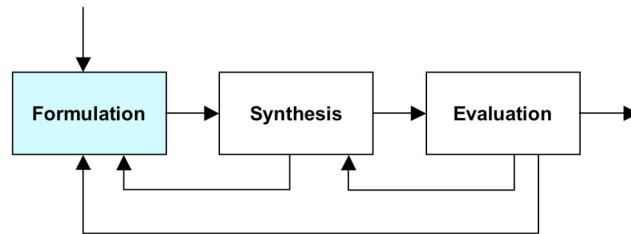


Figure 2.2: A generalised three-phase design process model

As can be seen from Figure 2.2, in a generalised three-phase design process model although there is potential for iteration between the three phases, there is also an inherent order in which it is understood that designers approach a design problem. The phases are progressive and design generally commences with the problem formulation phase, followed by the synthesis phase, and then the evaluation phase. A brief explanation of each of the three phases follows:

- ▶ Design formulation involves taking the original ill-structured design problem or design brief and generating explicit design goals.
- ▶ Design synthesis involves identification of potential design solutions.
- ▶ Design evaluation involves judging the validity of the solutions in terms of how well they meet performance requirements.

Transitions between phases occur as the designer works from a general ill-structured concept to the final solution or design representation. Because requirement statements are “incomplete, inconsistent, imprecise, ambiguous and/or impossible”, designing can be properly distinguished from other kinds of problem solving such as “configuration, diagnosis, language understanding, doing mathematics, planning, scheduling, playing chess etc” (Smithers, 1998, pp. 5-6).

Maher (1990) describes the generalised domain independent three-phase design process formalism as originating from work relating to implementation of goal-orientated artificial intelligence techniques. However real-life problems typically resist scientific generalisation due to the contextual and domain knowledge interdependencies inherent in their framing (Waks, 2001). Consequently, the approach has shifted to articulation of

domain dependent process knowledge approaches. Domain specific applications follow from the understanding that both formulation and synthesis rely on the structuring of domain knowledge into different types with different roles. Domain specific knowledge is critical to formulation of requirement statements and to the synthesis of a solution, which satisfies some or all of the initial requirements. Additionally, evaluation also depends on domain knowledge.

2.3.4 Design as a set of reasoning tasks

Design reasoning can be viewed as the actions, steps, stages or operations used in the process of designing an artefact. Design actions can thus be broken down or decomposed, using task analysis, into components or subtasks to better understand the reasoning involved. For instance, Langen (2002) views the construction of a description and the determination of (additional or substitute) requirements of the artefact, and the strategic co-ordination of these activities as central to the act of designing. Thus, the process of design reasoning involves the actions required to consider, understand and draw conclusions about the design problem, task stage and expected end products.

The process of design reasoning commences with how the design problem is named and/or framed; in other words, it sets the boundaries or space under consideration. The naming and framing of the design *problem space* determines how designers focus and thus determines how problem and solutions are conceived (Schön, 1991a). Design focus in turn determines how problems are clustered, decomposed, transformed and prioritised as the design process proceeds. Design reasoning always occurs in a particular context so goals, media and knowledge selected must also reflect this in order for the design solution to adequately satisfy its specific contextual requirements.

In the previous discussion of the design process, a generalised map of the design process with formulation as the starting point for design was referred to; however this fails to adequately indicate the *decision sequence* and the recursive nature of the design process. Two architectural scholars, Tom Marcus and Tom Maver (as cited in Lawson, 1997), elaborate on the basic three-phase design process model in Figure 2.2 to better illustrate the reasoning sequence. The Markus/Maver design decision process model is illustrated in Figure 2.3.

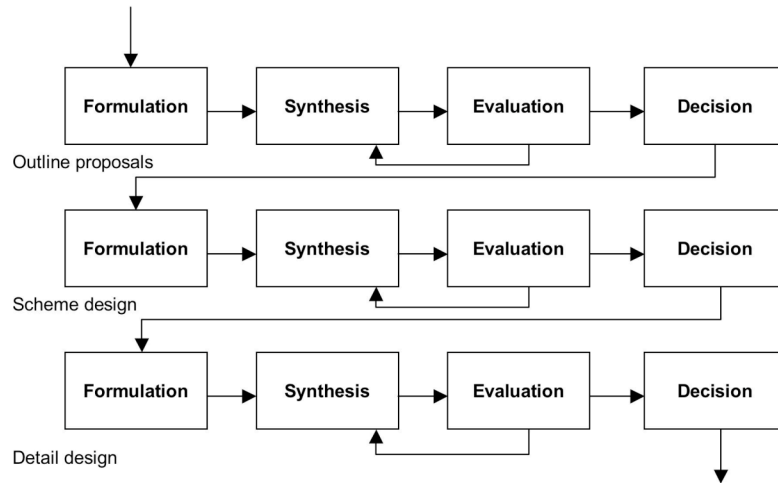


Figure 2.3: The Markus/Maver design decision process model (adapted from Lawson, 1997, p.35).

This diagram, while clearly iterative, fails to show feedback between levels and it is unclear whether the loop back between *synthesis* and *evaluation* reflects design reformulation or not. A design decision process model is significant to this discussion because, in this diagram, it is clear that a designer can only commit to a design concept at design process commencement when the design is far from being a physical reality.

The final design solution as currently understood depends on a series of design decisions that commence with appreciation of context, purpose, scale, form, style, precedent etc. and requires a familiarity with structures, technologies and processes used in construction. Design products thus depend on prioritisation and resolution of often competing goals at each phase of the design process. This means, that all prior design reasoning commitments or decision choices shape the final design product. While this may appear obvious, this insight remains critical to improvement of both design and redesign outcomes, because if design reasoning fails to adequately place artefact usage in a human context by inadequately capturing and attending to human and activity variance, design process outcomes will also be lacking.

In the Markus/Maver diagram, the initial phase for all three-design stages was labelled *analysis* not *formulation* as presented in Figure 2.3. According to Lawson (1997) “analysis is the ordering and structuring of the problem” (p. 35), that allows the exploration and classification of relationships. I have chosen to use the word *formulation* here because, despite minor semantic differences, *formulation* like *analysis*, encompasses understanding the problem and *formulation* is the preferred term used by other researchers describing design process models (Maher, Balachandran, & Zhang, 1995).

The Markus/Maver diagram describes the design process as a movement from conceptual *outline proposals* to concrete *detail design*. Within design process models there is an inherent order in movement between the stages. Design actions reflect this progression, with each cycle reflecting a more detailed and less general movement from the initial conceptualisation to the final design specification or product detail stage. This implies that early stages are concerned with feasibility and later stages with product detail (Lawson, 1997).

In this sense, design as an activity can be said to be an abstract series of decision actions or *design moves* that commence with the analysis of a general concept. The recursive process of design actions or moves combined in a sequence results in a final design product. Schön specifically chooses to use the word *moves* because of its association with gaming. In this sense he means that a “designer’s moves tend, happily or unhappily, to produce consequences other than those intended” (Schön, 1991a, p. 79). This implies that design modification or *redesign*, as an activity is an intrinsic part of the overall design process. As new understandings and appreciations are made, new moves occur, so iterations flow from a previous action and each new action involves consideration of increasingly specific design detail.

The Markus/Maver model however is not unique in elaborating greater levels of detail in an attempt to systemise and formalise the reasoning behind the design process. Dym’s model illustrated in Figure 2.4 was developed for application in the domain of engineering design. It presents a more detailed model of the design process and is considerably more complicated than the Markus/Maver model.

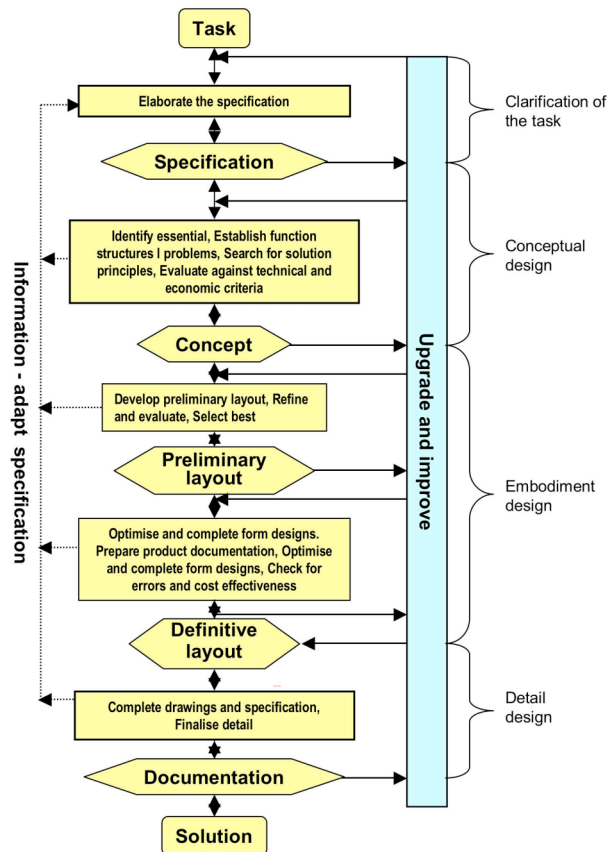


Figure 2.4: Detailed model of the design process (Dym,1994, p. 31).

Dym's model uses the principles of process flow to identify four design subtasks or stages.

- ▶ Clarification involves taking an ill-structured *task* and deriving a *specification* of design goals towards which success can be measured.
- ▶ Conceptual design involves prioritising often competing goal *specifications* or establishing a *function structure* in order to identify the appropriate design method that can most economically resolve the problem. The output is the design *concept*.
- ▶ Embodied design involves taking the design *concept* through the initial *preliminary layout* stage to the output stage that is a *definitive layout*. This is achieved by refinement and evaluation and involves both ranking and selection.
- ▶ Detailed design involves the final phase of *documenting* the definitive layout as a design *solution*.

This model, the most elaborate of those presented so far, is still insufficiently detailed to differentiate the problem solving techniques and knowledge best suited to each subtask.

As Dym makes clear, elaboration in itself is not beneficial; what is required is the ability to “understand and model the separate tasks done within each phase of the design process” (Dym, 1994, p. 33).

Implicit in the design process models so far examined is the management and transformation of information. Transformation or design reformulation do not appear in most traditional models of designing but are critical (Gero, & Kannengiesser, 2002).

Design proceeds by transforming and adapting knowledge from earlier task stages. Reich (1991) believes that understanding the issues in design knowledge requires a systematic analysis of the design task so subtasks can be executed sequentially. Reich presents a structure for design tasks, which is unique as a design process model because it explicitly refers to redesign as a design subtask stage (see Figure 2.5).

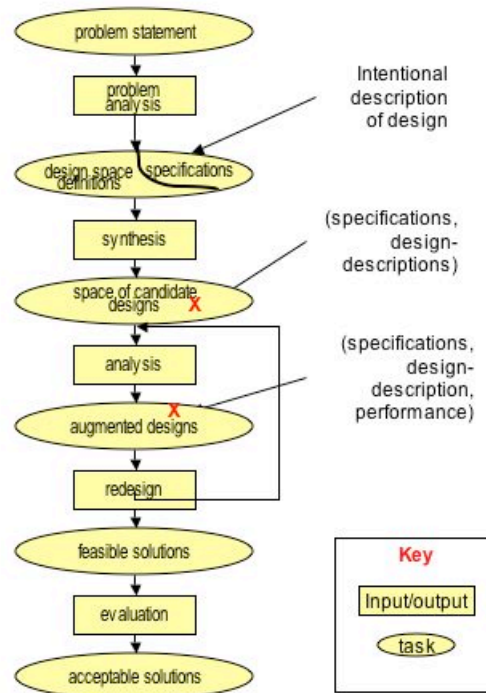


Figure 2.5: A five-task generic design process model (Reich, 1991, p. 240).

Reich’s concept of redesign involves a distinction from the more general evaluation subtask and has its basis in the need to resolve artefact inadequacies. In identifying redesign as a specific and unique design subtask, Reich makes the case that the redesign task has particular knowledge and problem solving techniques that can and should be conceptually distinguished.

The five-task generic design process model illustrated in Figure 2.5, like the earlier prescriptive model, also uses the principles of process flow to identify unique design

subtasks. The ‘x’ indicates particular specifications within a larger space of possibilities. The fix boxes are the input/output and are more fully understood as follows:

- ▶ *Problem analysis* involves better understanding the problem to allow formulation of specific design goals. This is dependent on modelling. Modelling drives negotiation and uses general problem solving (i.e. common sense) and domain specific knowledge to define or bound the potential design search space.
- ▶ *Synthesis* involves application of search techniques to explore potential solutions that might satisfy specifications. Synthesis is conceived of as a generative process dependent on control knowledge that encompasses transformation from intentional to extensional design descriptions.
- ▶ *Analysis* involves application of domain theory to make explicit classifications regarding performance criteria so candidate designs can be measured and inadequate designs identified.
- ▶ *Redesign* involves applying causal and heuristic knowledge to resolve artefact inadequacies by proposing a diagnosis or interpretation of design modifications.
- ▶ *Evaluation* involves selecting the most feasible design solution by ranking and prioritisation of candidate solutions.

Despite their differences, all the models of the process of design reasoning examined here have identified task stages and specified an expected end-point that results in a detailed design product or representation. Similarities and differences in the models are summarised in Table 2.2.

Table 2.2: Similarities and differences in design process models

Similarities	Differences
▶ All design process models take an ‘ill-structured’ initial starting point or concept.	▶ Some minor semantic differences i.e. ‘Formulation’ versus ‘Clarification’ and ‘Problem analysis’.
▶ Design goals are formulated in abstract fashion, with movement from general outline to design details i.e. artefact or component description.	▶ The specification of phases or subtasks within models is dependent on purpose, knowledge and techniques.
▶ The search space or problem frame is open to reconceptualisation. In other words, all design process models are inherently recursive in nature.	▶ The degree of reconceptualisation depends on the prescriptive evolution of the design. In other words, as the design process progresses or as design decisions accumulate the degree of reconceptualisation decreases.

2.4 Redesign and redesign models

What is the relationship between design and redesign and is redesign a simple subset of the design process, or an activity with distinctive knowledge and processes of its own? To answer the first part of the question, the concept of redesign is reviewed. Following this review, an examination of the relationship between design and redesign follows to address the second part of the question. Lastly, how design and redesign differences are characterised in terms of product and process specifications is explored. Clarity regarding the task of redesign makes practical any attempt to model case-based redesign reasoning. Redesign modelling mandates that all critical components can be decomposed, articulated and computationally formalised.

Redesign reasoning is commonly understood to be a form of transformational problem solving. Transformations based on reuse of past precedents or analogical reasoning are required to adapt artefacts to the new requirements. Redesign has been defined as an act that requires “decomposition of an old design followed by transformational design in an overall process often called hierarchical design” (Wilson, 1989, p. 217). Hierarchical design implies some sort of abstraction hierarchy with concepts being broken down into smaller components at lower levels. As Dym points out, “*Decomposition* or ‘divide and conquer’ is a way to reduce a large problem into a set of smaller and presumably easier sub-problems” (Dym, 1994, p. 38). Moreover, the ability to distinguish hierarchical components is essential to many descriptions of physical and/or abstract systems, including design and redesign at both product and process levels (Wijngaards, 1999). Redesign thus requires an understanding of compositional relations, which implies decomposition or separating (a particular object or instance) into its base elements.

Decomposition in this context is akin to the engineering discipline of reverse engineering whereby a product design or otherwise, can be decomposed into a functional hierarchy of some sort to better understand interactions between subsystems, design constraints and physical principles (Aiken, 1998; Ajila, 1997). Reverse engineering involves decomposing an original design at system and subsystem levels to find out what components are involved, their functions and how components might be improved or adapted (Otto & Wood, 1996). Redesign decomposition involves decomposition of a real world artefact, not just a decomposition of design requirements. Thus redesign decomposition requires very concrete representations of artefact components. In this sense, Wijngaards (1999) distinguishes redesign from design as a refinement that requires greater levels of specificity in both knowledge and process.

2.4.1 Redesign versus design: Articulating relationships

When attempting to analyse the differences and similarities between redesign and design it is intuitively obvious that they relate and possibly exist on some continuum but exactly what the relationships are is not altogether clear. Establishing the relationships between design and redesign presents difficulties, as several potential relationships require consideration. As we have already seen, some models of design process previously examined explicitly include redesign as a specific design subtask. Diagrams such as Venn diagrams are potentially useful in assisting visualisation of subset relationships. Possible relations can be expressed as either redesign being a design subset or a separate entity, which partially overlaps with design. On the other hand, an alternative perspective views redesign and design as existing on a continuum where they are at opposite ends so have distinct and unique features.

Figure 2.6, shows redesign as a subset of design. For this type of relationship to hold true, all the process and components of redesign reasoning would be true of design, but some components of design reasoning would not belong to redesign. This appears to be the typical approach to redesign reasoning as articulated by current research (Reich, 1991; Wijngaards, 1999).

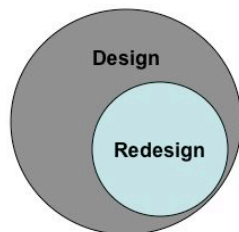


Figure 2.6: Venn diagram showing redesign as a specialized subset of design.

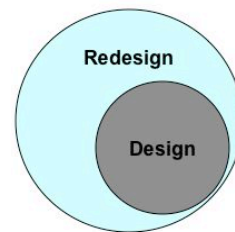


Figure 2.7: Venn diagram showing design as a specialized subset of redesign.

However, while the relationship depicted in Figure 2.6 is helpful for understanding redesign as a design subtask differentiated solely by greater levels of specificity, it does not adequately consider the implications of redesign as a starting point in itself. If this model of conceptual relationships were valid, it would imply that all existing design product and process models should be equally valid to a redesign task. For instance, we can imagine a set of processes tasks 'a', 'b', 'c' and 'd' belonging to design, of which only process task 'd' belongs to the redesign subset. What we cannot logically imagine is that redesign possesses a process task, 'e', that does not belong to design.

Nevertheless, redesign is a common starting point, especially in architectural and engineering modification and/or remodelling work, which is usually undertaken when an

existing artefact fails in some manner to meet requirements that were omitted or poorly anticipated in the original design (Michl, 2002). For example, the design of motorcar controls assumes that drivers will operate the steering wheel, windscreen devices and turning indicators using their hands. This design is fine for the average user, but redesign might be required to suit drivers who must use their feet instead of hands. The starting point here is not a concept but the artefact itself; in other words, specific car components designed to be operated by human hands. In this case, the operational components require consideration from the perspective of the needs and abilities of this non-average driver, which then leads to a reconsideration of the artefact features and their compositional nature.

The starting point in this example is thus not *formulation* but *evaluation*. The reasoning is concrete not abstract. In other words, we are uninterested in the chassis or the internal wiring unless there are implicit compositional arrangements that will affect our modifications and we cannot anticipate this without knowledge of the original design. Knowledge of the original design is needed to guide decomposition of components and component relationships. Redesign reasoning is, in this sense, primarily about particular components and their compositional arrangements. The redesign problem is also, in this sense, more *structured* than a design problem where more initial energy is expended on *formulating* goals or narrowing the starting frame.

Figure 2.7, shows the reverse situation where design is a subset of redesign. For this type of relationship to hold true all the components of design reasoning would be components of redesign reasoning, but there may be components of redesign reasoning that are not components of design reasoning. As Michl (2002) points out, while in one way it is correct to say that designers start from scratch it can also be argued in practice that designers always start from where other designers have left off.

Michl's conceptualisation of redesign is that design emerges as a sub-category in a continuously evolving process of redesign. This perspective might imply that design, as a specialized subset, would not be applicable in all the same contexts as the more general and higher order notion of redesign. However, this is intuitively incorrect and does not coincide with other current research and implies that redesign could occur without design products or process as a basis. In fact, Michl concludes by arguing for both design and redesign perspectives as being of equal validity, his key point being the undervaluing of redesign as the more common but less prestigious activity.

A comparison of the two diagrams supports the notion that redesign can be thought of simply as a subset of design. In other words, the same processes, but applied to a

narrower subject area. However this conception fails to consider the possibility that some process tasks may be specific to redesign that do not occur in design. So far, our exploration has been of superordinate and subordinate relationships, neither of which sufficiently differentiates the relationship of design to redesign.

Design as previously discussed can lead to redesign either as a subtask or as a separate activity resulting from new requirements becoming evident. However, it is also true that redesign can lead to design in the sense that the required changes are so drastic that radical structural alterations may be needed. The consideration of compositionality of components required by redesign can reduce reconceptualisation to a point where the problem may become intractable and in this case, design from scratch may be considered more feasible (Chandrasekaran, Goel, & Iwasaki, 1993).

2.4.2 Redesign and design as distinct but overlapping

An alternative view of the relationship between design and redesign is that they share some of the same reasoning components but that they are in reality quite different. This type of relationship is illustrated in Figure 2.8 and Figure 2.9. For this relationship to hold true, there is an expectation that some crossover or overlap will occur, thus only some of the components of design reasoning will be applicable in the redesign context and vice versa.

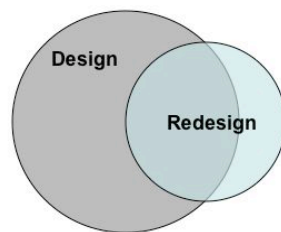


Figure 2.8: Venn diagram showing redesign as a smaller set of concepts and/or prototypes than design

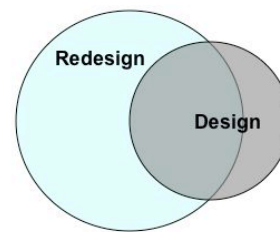


Figure 2.9: Venn diagram showing design as a larger set of concepts and/or prototypes than redesign

The only difference between Figure 2.8 and Figure 2.9 is a difference in perspective as to the degree of overlap and/or differences in the primacy of the domain covered by the concept. In Figure 2:8, design has the largest domain while in Figure 2:9 it is vice versa. Primacy of the domain is not an issue for this research, as the point of differentiation is purely to clearly articulate fundamental characteristics of a redesign framework capable of explicitly representing redesign knowledge. The key research issue in terms of the framework outlined in this thesis is in exploring what product or reasoning process

components might be the same and what reasoning and process components might be different.

Design and redesign obviously share a number of properties. Product representation in both domains requires compositional systems for description of input, output and reasoning (Wijngaards, 1999). In addition, typical problem solution processes such as synthesis and evaluation as recursive process tasks are equally applicable across both domains.

2.4.3 Redesign and design as distinct but interconnected

If difference in process and product components result from variance in starting points (i.e. design processes moving from the abstract to the concrete while redesign processes moving from the concrete to the abstract), it is still possible to view design and redesign as interconnected. The interconnectedness becomes apparent in situations where redesign is deemed infeasible and design must begin again from scratch, and/or where design components are evaluated as not satisfying performance requirements and so require redesign.

Redesign may be thought of as a problem solving process that is more constrained than design problem solving. Additionally, while redesign appears to be embedded in design, redesign occurs as an activity by itself and some might argue occurs more frequently as the degree of design originality and the use of precedent implies possibly only a limited number of designs really occurs from scratch. Wasserman (2004) for instance feels that many creative works stem from reinterpreting original designs. Further, a more careful re-examination of design and redesign definitions reveals differences between design and redesign.

Table 2.3 highlights these differences. These characteristics will be expanded on more fully in the examination of redesign product and process following.

Table 2.3: Characterising differences between design and redesign

Design	Redesign
<ul style="list-style-type: none">▶ Ill-structured problem, generalised goals as starting point▶ Commences with abstract reasoning▶ More generic knowledge▶ More generic processes▶ Environmental context more variable	<ul style="list-style-type: none">▶ Better structured, artefact or component based starting point▶ Commences with concrete reasoning▶ More specific knowledge▶ More specific processes▶ Environmental context less variant

This comparison between design and redesign definitions indicates that the difference is not in satisfying goals but in the level of goal specificity, transformational processes, decomposition strategies and the initial starting state. In contrast to design, the starting state in redesign is the product itself and reasoning involves the identification of functional mismatches prior to transformation, resulting in a new product description. In addition, existing design models, at best, only implicitly represent redesign knowledge with the consequence that redesign learning has never been captured or made available for reuse.

2.5 A new model of redesign

The difference in starting point between design and redesign means that problems are named, or as Schön (1991a) would say, framed in different ways. Articulation of differences shows that design and redesign have a different starting point. The starting point is critical to the *product* and *process* models required.

The elements of redesign can be defined as the:

- ▶ new user design requirements;
- ▶ set of existing design product components; and
- ▶ knowledge of how components are related.

If the redesign goal is to *integrate* the new user requirements with the existing design product components, then existing design process and product models are clearly inadequate for achieving the specifying component relationships and consequently for enabling computational representation. Developing a new model of redesign that can achieve this has the potential to improve redesign reasoning outcomes, by underpinning the task stages undertaken and better capturing the level of specificity and potential for variability within the redesign problem frame.

2.5.1 Redesign as a product

Redesign starts with the output of the original design process and input about the new properties required. Representation of the redesign product thus inherits compositional systems that result from design process outputs. Thus redesign products benefit from and/or can share computational formalisms for describing and decomposing design products. However redesign products also need to capture specific redesign knowledge typically absent from existing design models, these include the:

- ▶ changes to requirements that prompted the redesign;

- ▶ modifications or changes made (only part of a product assembly may have been changed and it may be more economical to represent only those features); and
- ▶ component sub-systems interdependent with and impacted by changes (many of which may have been implicit prior to the redesign process).

Thus, redesign as a product description has additional and specific requirements over and above those evident in traditional design product descriptions. Redesign product formalisms require additional explicit representation of redesign knowledge *to support* redesign reasoning. Let us return to the car control redesign scenario mentioned previously. Additional product description knowledge is needed for evaluation and review. This additional redesign product knowledge is illustrated in Table 2.4.

Table 2.4: Example of a simplified diagrammatic representation of the product knowledge components needed when reasoning about the redesigning of car controls

Redesign Input	Redesign Output
<i>New requirements</i> for steering (i.e. steering = foot_operation).	<i>Redesign problem label</i> (i.e. steering_redesign = hand_operation-changed-to-foot_operation).
<i>Design component descriptions</i> (i.e. descriptions of car components relevant to original design output: <ul style="list-style-type: none"> ▶ degree_of_rotation-of-steering ▶ hand_operation-of-steering ▶ type-hand_wheel ▶ hand_wheel-shape ▶ hand_wheel-size ▶ hand_wheel-material ▶ hand_wheel-height 	<i>Redesign component descriptions</i> (i.e. add, remove, substitute, repair, reposition type output: <ul style="list-style-type: none"> ▶ <i>remove</i> = hand_operation-of-steering ▶ <i>substitute</i> = foot_operation-of-steering ▶ <i>add</i> = type- foot_toggle ▶ <i>add</i> = foot_toggle-shape ▶ <i>add</i> = foot_toggle-size ▶ <i>add</i> = foot_toggle-material ▶ <i>add</i> = foot_toggle-position
<i>Design component composition descriptions</i> (i.e. descriptions of car components relevant to design) <ul style="list-style-type: none"> ▶ mechanical system ▶ electrical system ▶ body system 	<i>Compositional subsystems affected</i> (i.e. descriptions of car components relevant to redesign disassembly and/or reassembly of related steering subsystems: <ul style="list-style-type: none"> ▶ steering column system ▶ wiper system ▶ indicator system ▶ chassis system

Redesign product description can be viewed as an extension of product design formalisms that allows manipulation and reuse of redesign knowledge. For this purpose, redesign requires the articulation of sets of requirements as well as explicit representation of modifications undertaken and the compositional interdependencies uncovered.

2.5.2 Redesign as a compositional system

If design products are conceived of as compositional in nature, redesign products must also be compositional because design product descriptions provide initial input. Figure 2.10 illustrates the compositional nature of the input and output knowledge required by the redesign process.

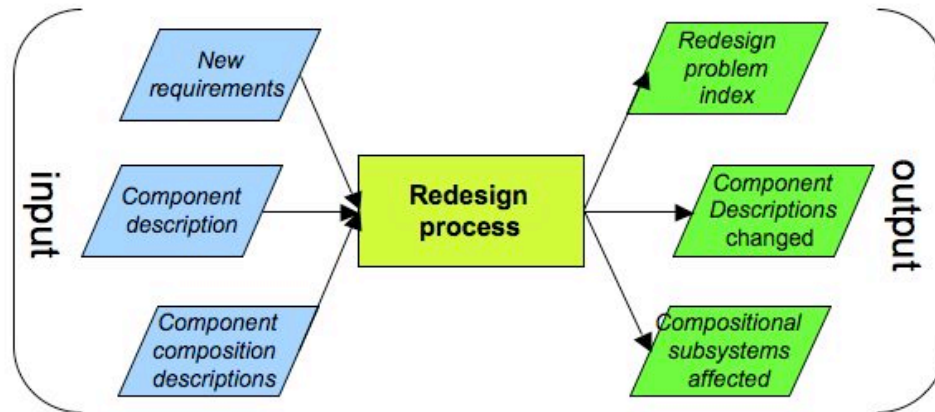


Figure 2.10: Simplified view of compositionality of redesign input and output

Commencing the process of redesign evaluation requires representational formats that can be decomposed to the lowest sub-component level. According to Wijngaards (1999), the critical difference between design and redesign input and output knowledge is the increased specificity required of redesign knowledge representations.

2.5.3 Redesign as a process

Implicit in the redesign process differences so far examined is the management and transformation of information. Like design, redesign proceeds by transforming and adapting knowledge from earlier task stages. Exploration of the implications of the starting point, nature of goals, environmental context and the reasoning type is presented so as to better understand the implication of these differences and to facilitate selection and integration of existing design models for application to redesign modelling.

To better illustrate these differences, practical examples will be interspersed throughout the following analysis. The redesign of a bathroom space (i.e. a small part of a housing unit or office) serves as a suitable illustrative example because it is less complex than the majority of stand-alone built environment artefacts such as high-rise offices, schools or housing developments but has sufficient complexity to clearly demonstrate relevant redesign differences.

2.5.3.1 Starting point

The starting point for design and redesign are different. The redesign problem frame commences with an actual product. The product itself needs to be understood and a mental representation created for potential solutions to be generated and explored. For instance, redesign of a bathroom requires that the problem can be understood and that salient aspects can be framed by knowledge of existing structures, fixtures, fittings and their interrelationships.

The existing bathroom space, bounded by walls composed of specific materials, has certain properties and may or may not contain services such as plumbing and wiring. Decisions to extend the space or to relocate objects within the space are always constrained by knowledge of specific structures and their corresponding behaviours and functions. This specific knowledge needs to be represented in order for interaction of variables to be understood.

More importantly, actual products have a three-dimensional reality, which requires a process of representation and decomposition to a component or element level. To evaluate the effectiveness of redesign on actual components, you have to consider the specific structural, functional and behavioural attributes of each component in conjunction with the new requirements. For instance, redesign of a bathroom component, such as a toilet grabrail, requires consideration of the position, shape, profile, length, slip resistance and grabrail interdependencies with other bathroom components such as fixings to surfaces. Analysis of goal satisfaction involves consideration of grabrail interdependencies with other components such as fixings and surface type in conjunction with the height, grip strength and abilities of its intended users.

In contrast, the initial design phase is unconstrained by particular product selections, fixings and connections. Problem representations are based on more general specifications in the form of a brief and knowledge of a set of performance codes to be satisfied. For instance, the number, type of bathroom and physical location may be changed any number of times throughout the design process in response to other issues associated with cost, style, potential market and/or changes in client related specifications. The designer may or may not consider provision of an en suite with a spa area, given a brief that indicates that cost is no object, luxury standard or sensational view with privacy are expected.

Both design and redesign processes can be seen to involve abstract reasoning, concrete restrictions, a limited freedom of movement, practical consideration of materials, costs,

and interdependent relationships. Nevertheless, fundamental differences remain between the two, both in the degree of constraint and in the degree of product composition focus.

2.5.3.2 Nature of goals

As we have already seen, design goals commence as a statement of general intent about a concept and only become specific as design decisions are taken and reasoning progresses. Design goals usually relate to an initial conceptualisation of the product. For instance, most bathroom design centres on the creation of a space capable of fulfilling certain performance-based criteria to do with providing, containing, and draining water for body cleansing. The goal of providing water leads to the generation of other sub-goals, such as resisting damp and mildew, and so on.

In contrast, redesign goals are more constrained. If we consider the redesign of a shower to accommodate a person with a transfer or dynamic balance impairment, the redesign goal becomes one of modifying or eliminating the negotiation of any changes of level. For instance, elimination of the hob that is traditionally employed to prevent water leakage from a shower stall directly reduces the joint range, muscle strength or dynamic balance required. Thus redesign reasoning actions, are bound by what has already been provided. For instance, decisions pertaining to the removal of the hob will depend on the *existing* compositionality, structure and material of the hob itself and the degree of floor slope, floor coverage and drainage arrangements, i.e. availability of a floor drain, waterproofing membranes and area. Goals are limited to redesign actions that modify existing elements, add elements, remove elements and/or some sort of combination of these process moves. In some extreme cases, these moves are insufficient to produce a satisfactory redesign solution and so redesign is abandoned and design from scratch is required instead.

2.5.3.3 Role of environmental context

The role of environmental context is another aspect that separates the design from the redesign process. In design, the environmental context is open to reconceptualisation and is dependent on where a particular design decision sits within the sequence of design actions already made. So while a building designer cannot change the climate, orientation of the site or adjacent buildings, there is still the ability to design structures that work within these relatively loose constraints. However, as the design task proceeds and commitments are made the decision-making becomes increasingly constrained (Schön, 1991a). For example, in the bathroom instance, the final location and number of bathrooms provided is likely to be reconceptualised because of other prior design decisions. In this case, increasing the size of the bedroom may make provision of an en

suite impossible or the change in position of the door may flow on to affect where the toilet pan is located.

On the other hand, in redesign, environmental context is much less fluid. Redesign is always more tightly constrained than initial design. Redesign solutions are always generated in the context of an existing product, product connections and component interactions. Redesign of a toilet pan for instance, requires consideration of the horizontal and vertical space required by the existing product and its replacement, plus how it can connect to existing services and other components, such as the plumbing, cistern and seat. Moreover, to ensure that modification, removal or replacement is able to meet performance criteria, the relationship of other components not directly associated may also need to be considered (e.g. the location and placement of the toilet roll holder).

2.5.3.4 Reasoning type

Design reasoning concerns the creation of artefacts to attain goals, and is open to reconceptualisation as the task proceeds and reasoning moves down subtask levels. It is only as the designer commits to a particular decision that product or artefact components become more specific and relationships between artefact components become rigid. Redesign reasoning on the other hand, starts at the product specification end and movement either remains specific or moves back to the general.

Redesign reasoning commences with product evaluation. Product evaluation involves performance appraisal of design components to detect performance failures.

Performance failures may not be a result of poor design but of a change in performance criteria due to changes in the design context. New performance criteria may have been created because of changes in social, cultural or physical requirements. Typically, bathrooms are redesigned to remedy performance issues associated with functional failures, the desire to accommodate newer technology or in response to changes in user needs.

Figure 2.11 (unlike Figure 2.2 presented earlier) highlights a difference in sequencing of process phases with evaluation, not formulation, as the starting point. In redesign, the evaluation phase involves judging the components of the original design solution solutions in terms of how well they meet the new performance requirements.

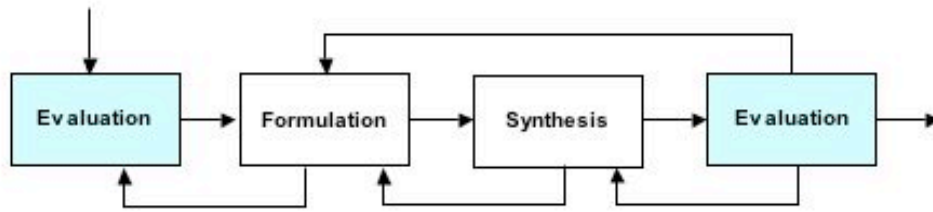


Figure 2.11: A generalised four-phase redesign process model.

Redesign reasoning can be said to be concrete because unlike design it starts with the product components and may involve repositioning components, replacing components or adding additional components to resolve the additional redesign goals and to improve artefact performance. For instance, redesign of a shower hob as previously discussed may commence with the evaluation of an existing product component, such as the hob itself.

The hob may be evaluated in terms of its location, height, surface and shape, because of changes in user requirements, making transfer in and out of the shower area potentially unsafe. Evaluation of a product judges the validity of component features relative to the redesign goal. In this case, improvements to safety are being considered that involve redesign to reduce the dynamic balance requirements on a particular user. Following from the evaluation phase, a number of redesign alternatives may be considered as part of the synthesis phase. In this case, an alternative that may be considered in the synthesis stage could include removal of the hob and replacement with a hob-free shower.

However, consideration of the hob-free shower alternative would require wider analysis involving impact on available circulation space, existing wall support structure and existing floor treatments. Thus, redesign reasoning requires movement from a specific product to its contextual situation. Movement runs from a component focus back to a more general level in terms of understanding the implications and interrelationships. In this case, analysis allows us to examine the dependencies and interrelationships between components. Thus, redesign reasoning moves out from the original component features to consider wider implications. Consideration of implications allows a better understanding of the problem and makes possible a more explicit statement of redesign goals. The feasibility of redesign as an activity depends on being able to evaluate the extent and scope of the changes required.

2.5.4 Redesign as a set of reasoning tasks

Fully understanding the issues in reusing redesign knowledge also requires a systematic analysis of the redesign task so subtasks can be executed sequentially. The analysis procedure facilitates an attempt at redesign decomposition. Having previously reviewed a number of formalisms (in some detail) to capture design characteristics, these same formalisms provide a basis for differentiating and articulating redesign characteristics. The model proposed by Reich (1991) was selected as a starting point because it comprehensively decomposes design process subtasks and because it was one of the few process models to reference redesign as part of its process decomposition. Figure 2.12 illustrates a reworked redesign reasoning subtask model, in which redesign is conceptualised as a five-task process closely analogous to Reich's previously depicted model of the design process. In the illustration, redesign reasoning flows from a previously acceptable design solution when new requirements are added.

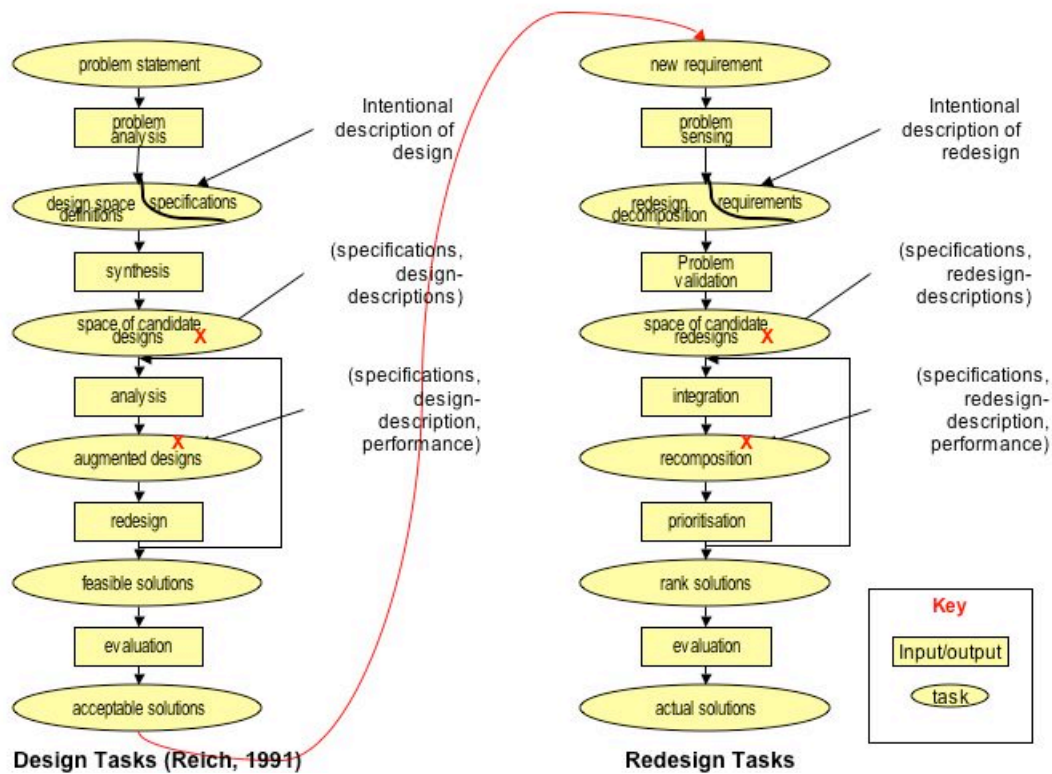


Figure 2.12: Comparison of design and redesign tasks

Some of the redesign subtasks in this model are quite distinct from the design subtasks. For instance, in the redesign process model, the input or starting point of redesign reasoning commences with new requirements in conjunction with the output of a previous design process in terms of a design product solution.

The redesign subtasks are briefly elaborated to better define the knowledge requirements and problem solving techniques involved.

- ▶ *Problem sensing* involves better understanding the new requirements in terms of mapping out the component subsets that are critical and in determining the relative importance of component interdependencies. This is dependent on domain knowledge and relevant ontology development.
- ▶ *Problem validation* involves diagnosis. Validation requires overt action in extending and testing understanding by mapping from assessment knowledge to the component product structures responsible for the problem. Validation confirms extensional design descriptions.
- ▶ *Integration* involves application of domain theory to make explicit classifications regarding constraint satisfaction so candidate component modifications can be measured and inadequate modifications identified.
- ▶ *Prioritisation* involves applying causal and in the absence of causality case-based or ‘rule of thumb’ knowledge to resolve artefact inadequacies by proposing a procedural order for consideration of components and component relationships.
- ▶ *Evaluation* involves selecting the most feasible redesign solution by ranking and prioritising any potential candidate solutions.

2.5.5 Implications for a computational redesign model

According to Alexander (1964), Simon (1973) and Schön (1983), design problems cannot be subsumed under a general category. Design applications are unique in terms of the function that the artefact to be designed has to fulfill, the real world environment in which the artefact is meant to fulfill this function, or both. As a consequence, available methods and techniques for known problem categories fail to effectively solve redesign problems.

Differences in redesign product and process descriptions impact computational implementation in a number of areas. Figure 2.13 illustrates how product, process and learning can be viewed as an integrated whole. Successful manipulation of these components requires that all three components be captured in some way, irrespective of whether the information is defined and manipulated by humans or automatically generated by a computer application.

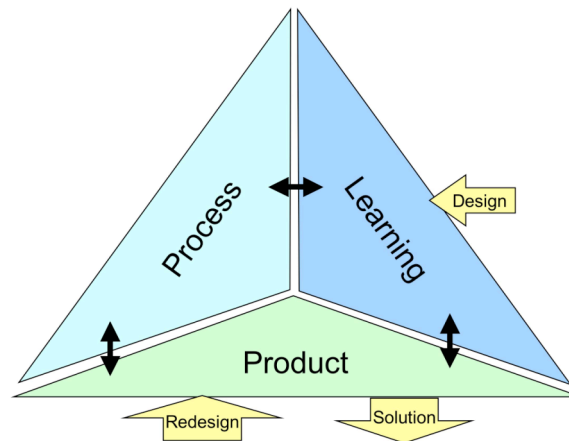


Figure 2.13: Key components for computational consideration in design and redesign illustrating different starting points but the same stopping point i.e. a product solution.

Specifically, the redesign product component knowledge requires the development of a suitable ontology that can be computationally represented. The product language selected needs to be specific to the intended domain of application (i.e. home modification). Once articulated, it forms the basic building blocks of communication shaping the interaction and feedback from the physical and mental worlds. Artefact descriptions in computational terms require machine processable representations of semantically rich information so salient features can be selected, retrieved and transformed as needed.

The process component, on the other hand, provides knowledge representation structures that guide transition through design stages or tasks. For instance, prescriptive process models, as we have seen, describe the specific actions required in an ordered way.

Last, but not least, the learning component indicates that a computational method or tool has to be able to capture facts about the world in such a manner that redesign learning occurs. Reasoning is a knowledge intensive activity and methods for storing and capturing knowledge allow manipulations and transitions between reasoning tasks or stages. Capturing and storing redesign knowledge enables reuse of that knowledge at a later point. As already discussed, design models, at best, only implicitly represent redesign knowledge thus redesign learning is lost.

2.6 Reflexive Summary

In this chapter an examination of the similarities and differences in reasoning and representation between design and redesign have resulted in clarification of the question *what is the relationship between design and redesign of spaces?* This knowledge is needed for a computational redesign system. The resultant list details the required

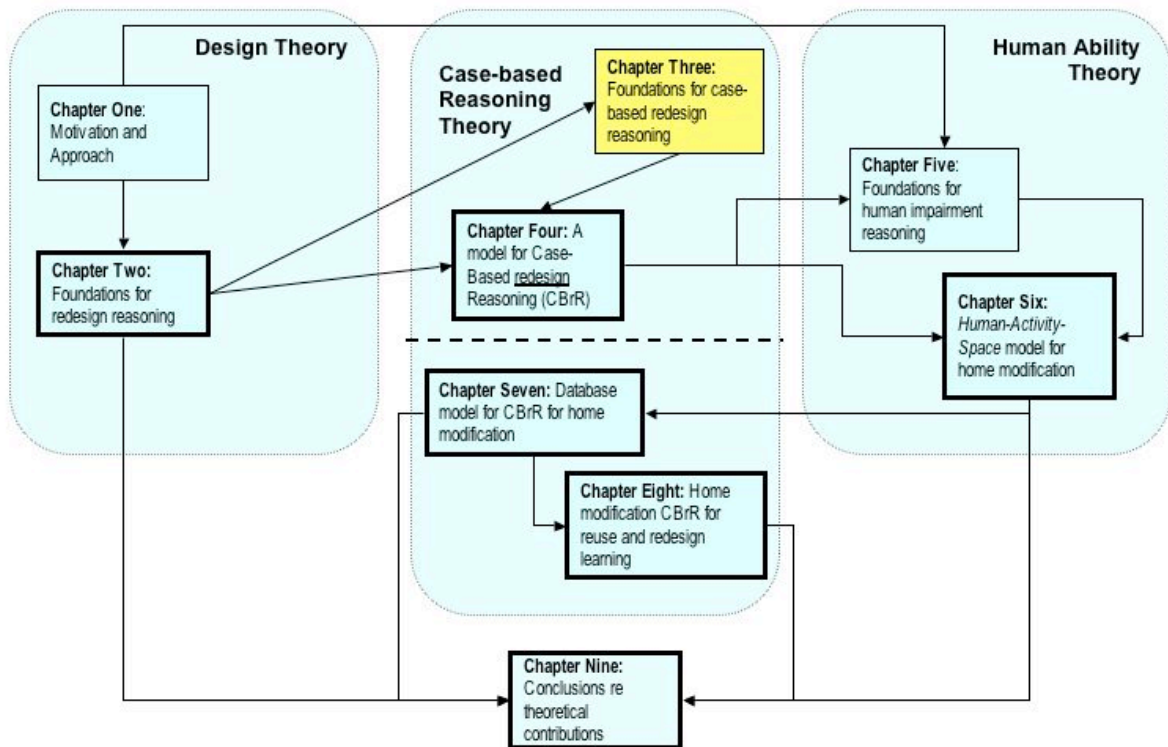
properties of a redesign process and product model. This knowledge will be used in the next stage of understanding what extensions will be required of case-based reasoner for it to operate in the home modification redesign domain.

What we have learnt so far is that:

- ▶ No representation structure for describing redesign products is available. Thus redesign product descriptions must be developed that capture requirements in addition to design component descriptions capable of representing the old design and the redesign solution.
- ▶ The redesign process differs from design component phases. Further, the distinct nature of the subtasks requires specific process knowledge and techniques to be applied concretely to a relatively fixed environmental context.
- ▶ No method of capturing and storing redesign learning yet exists. Therefore capturing and representing redesign knowledge during design reuse is critical. Further it has the potential to facilitate regularity tracking and enables exploration of component interdependencies.

In summary, the existing structuring principles for articulation of design product and process representation as discussed in this chapter were found to be insufficient to capture redesign characteristics needed for redesign reasoning. Thus, a framework for the description of a distinct redesign product and a new process of redesign reasoning are needed. The next chapter explores the application of case-based reasoning computational research to design reasoning in order to identify issues relevant to applying this approach to redesign reasoning.

3



Foundations for case-based redesign reasoning

Chapter 3: Foundations for case-based redesign reasoning

3.1 Introduction

This chapter sets out to answer the question: *what contribution could case-based reasoning theory make to redesign of spaces?* To achieve this, it reviews case-based design reasoning as a computational basis for redesign reasoning. Case Based Reasoning (CBR) theory and applications provide a foundation for developing a *terminological ontology* (i.e. vocabulary for expressing and classifying system parts) for the case-based redesign application.

Terminological ontologies are usually composed of three distinct parts: generic, domain and representation ontologies (Steve, Gangemi, & Pisanelli, 1998). *Domain ontologies* concern specialised knowledge in a domain or sub domain; in this instance, CBR in design and more specifically case-based design of buildings. *Generic ontologies* concern general foundational aspects of the reasoning process; in this instance, CBR itself. *Representation ontologies* specify the concepts that underlie knowledge representation formalisms.

A concise review of case-based design reasoning strategies provides a foundation for the redesign reasoning approach outlined in chapter four of this thesis. This chapter's structure provides an overview of case-based issues pertinent to representation and presentation, recall and adaptation of cases as a part of the CBR process. A review of computational strategies relevant to case-based design reasoning enables a global, external view and establishes some relevant similarities to and differences from case-based redesign reasoning. Thus, presentation of a general descriptive framework permits the teasing out of methodological issues relevant to case-based redesign.

3.2 The structure of this chapter

This chapter is structured into a number of parts to assist an understanding of case-based design reasoning as a process model. First, existing CBR foundations and knowledge inter-relations are explored. Second, explicit exploration of case-based design reasoning applications in the building domain and the techniques they employ regarding formalisation of building design case data, representation of building design cases and presentation of building design cases are examined and relevant advantages and limitations summarised. This facilitates an understanding and foundation for selection of particular techniques most suitable for representation and presentation techniques for redesign cases.

Third, case-based design applications and techniques are reviewed to better understand issues associated with recall, adaptation and learning in design cases. Consequently, case memory and case-part segmentation of building design cases, navigation of case memory, case retrieval, case selection and case acquisition methods and strategies are reviewed in order to identify research issues relevant to the development of a case-based redesign reasoner.

3.3 Foundations of case-based reasoning (CBR)

The basic concept of CBR as a computational methodology is to reuse prior experiences to solve new problems by recalling similar cases from a case-base by means of input queries (Kolodner, 1993; Leake, 1996). In computational terms, specifying the problem is usually accomplished by describing its elements. This data is the basis for recall and adaptation processes. In this sense “a case usually denotes a problem situation [and a] new case is the description of the problem to be solved” (Aamodt & Plaza, 1994, p 39).

Problem solving goals are achieved by applying case-based methodologies to recall old problem solutions for reuse. According to Leake (1996), generic case-based problem solving exploits two different types of similarity (i.e. those related to problem and solution spaces). This idea is illustrated in Figure 3.1.

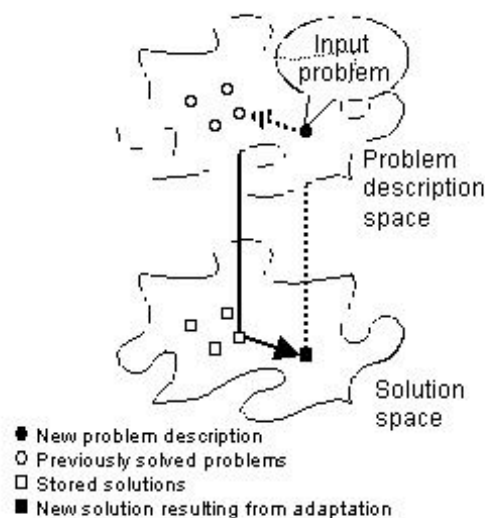


Figure 3.1: Basic case-based problem solving principles (Leake, 1996, p. 8)

Reasoning commences by taking an input problem and generating a problem description. The problem description starts the recall process by matching the most similar previously-solved problem. The solution that is linked to the problem description is then used as the starting point for solving the new problem. In most situations, the match is less than perfect and some form of adaptation is required.

CBR knowledge takes multiple forms, including the case episodes themselves and how they are represented/presented, plus the computational strategies used to recall and adapt them. Developing a CBR application thus means developing encoding, matching and adaptation strategies designed to facilitate reuse (Riesbeck & Schank, 1989). By retaining adapted cases or acquiring new cases, CBR applications learn incrementally: problem-solving knowledge evolves as the case-base increases. Thus acquiring a case can also be said to denote an *episode* around which learning occurs or from which lessons can be derived.

CBR differs from analogical reasoning in that case-based reuse is within a specific knowledge domain, not across knowledge domains. For instance, the design of a motor for a boat differs sufficiently spatially and functionally from the design of a motor for a train, car or aeroplane that any attempt at case-based reuse without substantial feature adaptation becomes infeasible. The basic assumption of CBR is that retrieving a similar problem and transforming the solution to fit the new problem parameters is less difficult than reasoning from first principles. CBR is an attractive problem-solving strategy when domain knowledge structure is poor and no strong domain theories exist (Bonzano, 1998).

Reference to prior case knowledge assists in identifying regularities and irregularities, making CBR an attractive model for storing and accessing knowledge in context (Maher, 1990). Maher points out that, in many ways, CBR mimics human problem solving. This view accords with the claim that when humans learn from experience they acquire cases, and that active interaction with prior cases enables new knowledge acquisition (Schank, 1996). For example, the design of a house historically involves certain culturally defined building types. In other words, each society has always had accepted 'prototype forms' which serve as models for construction. This effectively reduces the complexity of factors to be considered throughout the building process and, in most cases, simplifies communication and problem solving. Housing design draws on a knowledge base of prior case examples (Alexander, 1979; Rapoport, 1969).

3.3.1 Structuring of CBR tasks

To describe the structure of CBR tasks, many researchers have developed *task-method models* (Steels, 1990; Chandrasekaran, 1990; Aamodt & Plaza, 1994; Wielinga, Schreiber & Breuker, 1992). However Diaz-Agudo and Gonzalez-Calero (2002) claim that the most relevant work is the CBR task-method structure/model description originating from the work undertaken by Aamodt and Plaza (1994). Task-method models provide tools that enable analyses of CBR applications in terms of both the control knowledge and the method implementation used. CBR is generally represented as a cyclic process in which cases with the most features in common to the new problem scenario are recalled from the case-base or case library for reuse

or adaptation, and the new case (problem and solution) is then added to the case-base. At the highest level of generality there are two key reasoning processes involved in intelligent identification and reuse of prior experience. In CBR terminology they are sometimes referred to as *recall* and *adapt* (Maher et al., 1995) or alternatively as *retrieve* and *reuse* (Aamodt & Plaza, 1994; Watson & Perera, 1997a).

Aamodt and Plaza (1994) also describe another two tasks, captured by the terms *revise* and *retain*. Revise is primarily about evaluation and repair of the solution. However, retain refers to extracting, indexing and integration of new case knowledge. The researchers go on to decompose their four basic CBR tasks into subtasks that require particular methods. This subtask hierarchy is illustrated in Figure 3.2. In the illustration, part-of relations in a downward direction link all tasks and methods.

A more detailed description of the *retrieve* or *recall* task process is important in understanding the relevance of tasks undertaken by a system designer to enable a case base (i.e. the case memory) to be probed. Indexing, for instance, concerns the identification of critical features so that case-based retrieval is efficient and timely. In this same sense, it facilitates case acquisition by identification and labelling of new case features. Pattern matching, on the other hand, just refers to the process of using a set of identified features to extract cases that contain the same pattern of features.

Agreement exists that elaboration of CBR subtasks is both necessary and helpful. However terminological differences between researchers relate to more than just semantics as they imply different approaches to control and order of execution of subtasks. The revise and reuse subtasks described by Aamodt and Plaza (1994) have features that overlap with the more simple adapt task. Thus, in this thesis, the subtask descriptions from this point forward will instead follow those outlined by Maher et al., (1995).

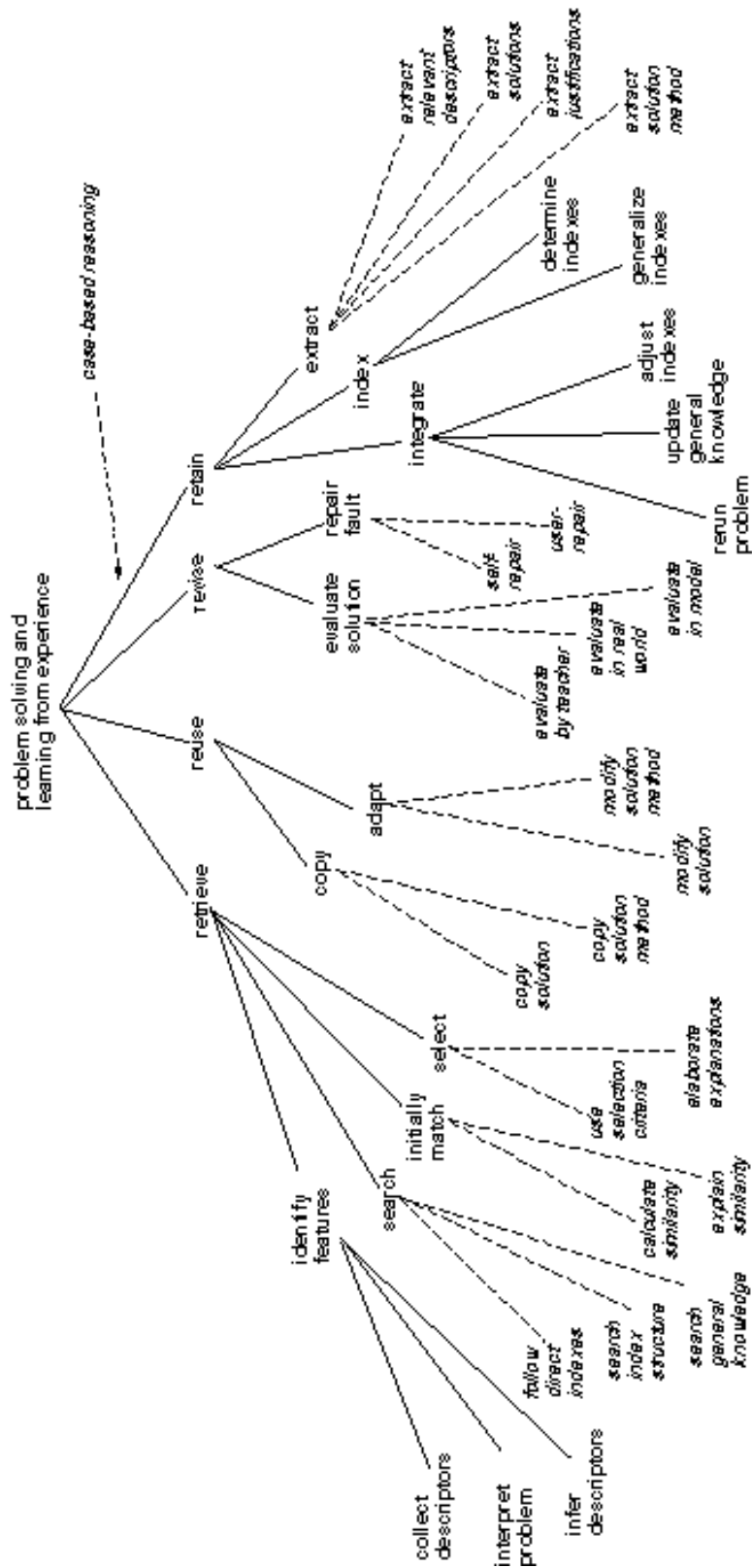
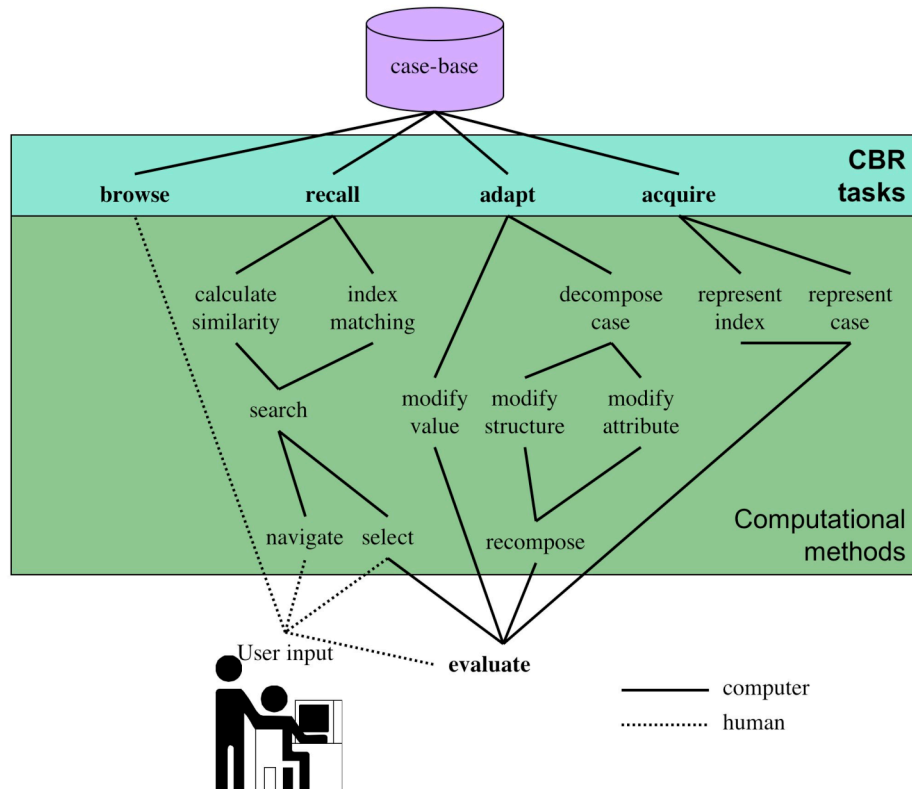


Figure 3.2: CBR task-method decomposition model (Aamodt & Plaza, 1994, p. 9).

Figure 3.3 illustrates the revised task-oriented view that underpins this thesis. The core goals of a case-based design reasoning (CBdR) system are the recall and adapt tasks; these,

however, rely on browse and acquire subtasks to better incorporate web-based learning goals. The computational methods indicate how the tasks are accomplished and the lines approximately indicate the procedural flow. However, the links in Figure 3.3 unlike Figure 3.2 are bi-directional, not all downwards, as many CBdR tasks rely on user input.



A human/computer task-method decomposition of CBR

Figure 3.3: Overview of user and case-based task-method relationships

CBR assumes a continuity of flow between process tasks; that is, the adaptation process modifies the case features that are unsuitable to the new problem situation. Adaptation typically requires extensive domain knowledge. However the type of knowledge required depends on the purpose and type of method employed. The modification undertaken during adaptation may mean altering case solution features or require substitution of feature values. The evaluation subtask can either take the result from applying the solution in the real world and note faults that require adaptation, or it can anticipate faults by checking legal values and/or using domain knowledge to predict constraint violations.

Because CBR operates directly on the case-base a key issue concerns methods for computationally defining the knowledge structure and representational data type(s) selected for storage of cases. The case-base represents knowledge in context, thus it requires careful organisation. Case-base organisation influences what can be recalled and then reused. The

practical issues involved in case representation are still largely unresolved. This is partly so because representation is largely domain dependent and because the computational methods available are continuously evolving. For instance, the concept of the semantic web being machine processable is relatively new (McGuinness, 2002).

McGuinness explains that web applications have grown at an astonishing rate and that we have moved from hard coding of web pages for human consumption to second-generation applications that use mark-up languages and are machine-readable. For machines to mine both what is in a case and what the information means, requires representational ontologies to specify term names and term meanings. How these sit in the whole spectrum of computational representational languages used in web semantics is illustrated in Figure 3.4.

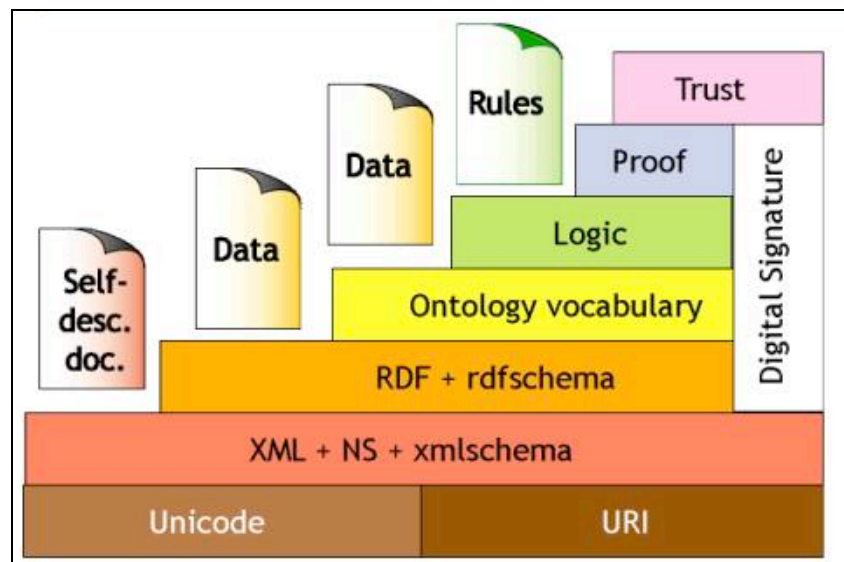


Figure 3.4: Berners-Lee's semantic web architecture (McGuinness, 2002, p. 2 online).

In summary, all CBR applications require explicit attention to the following tasks:

- ▶ case-based representation and presentation, which require both product and/or process domain knowledge;
- ▶ case-based recall, which requires navigation and search;
- ▶ case-based reuse, which requires feature deletion, addition or replacement; and
- ▶ case-based acquisition, which requires learning methods.

3.3.2 Interrelationship of CBR with other computational sub-domains

CBR has its origins in cognitive science and artificial intelligence, but has matured into a general problem solving approach with widespread application. Many techniques are 'put into

practice' in CBR applications, and because of its integrative nature, there are links to other computational development areas (Kamp, Lange, & Globig, 1998). Kamp et al. identify six application strategies that have links or crossovers with CBR (Figure 3.5). Of particular interest from the point of view of this thesis are the linkages with *information retrieval*, *knowledge representation*, *databases* and *machine learning*.

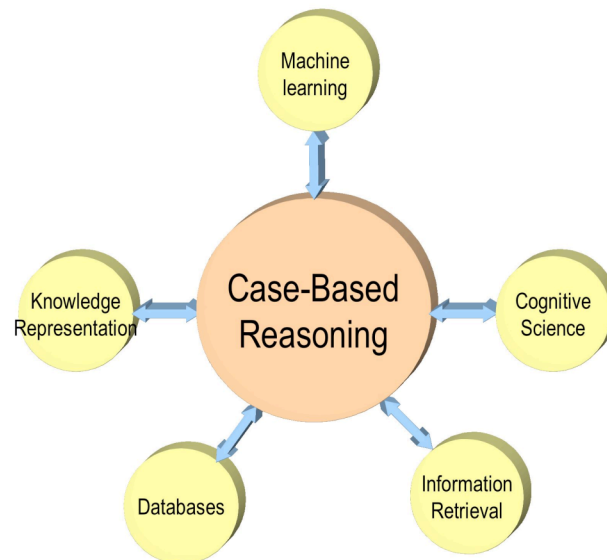


Figure 3.5: CBR and related areas (adapted from Kamp et al., 1998, p. 328)

CBR depends on intelligent recall. Information retrieval and CBR share techniques and goals but CBR applications typically process less data and use more knowledge-based retrieval strategies. However, more CBR systems are using textual data and thus *information retrieval* techniques, such as recall of free-form text, require consideration. Due to the explosive growth of Internets and intranets, a substantial number of CBR applications are now web-based. Web-based implementations require consideration of navigation and browsing facilities on top of the more traditional CBR recall strategies.

Knowledge representation in CBR borrows from artificial intelligence methodologies, but as CBR research moves into commercial and real world application domains, greater consideration of representation of structured domain knowledge becomes important. An intrinsic aspect of CBR process models is case storage. CBR is generally regarded as a subfield of machine learning. Automatically adding solved cases to the case-base means that learning in CBR is a by-product of the problem solving process (Aamodt & Plaza, 1994).

According to Richter (1998), CBR research centres on answering the following questions:

- ▶ What are problems and how are they represented?

-
- ▶ What does it mean to say that something is a *solution* to a *problem*?
 - ▶ What does it mean to say that something is *similar*?
 - ▶ How is *past experience* represented?
 - ▶ What does it mean to look for a *solution*?
 - ▶ How to use an old *solution*?

Because many of these answers are domain-dependent, in the next section case-based design implementations are examined and evaluated in terms of how they answer these questions or raise issues that need to be addressed in a case-based redesign reasoning application.

3.4 Foundations of Case-Based design Reasoning (CBdR)

CBR as a computational problem-solving model has been applied to support designers solving design problems. Certainly, many design researchers have now recognised CBR as a plausible means of modelling the design process and as a promising methodology for design systems. There are now many case-based design systems described in the literature. This now quite well established field of research has become known as Case-Based design Reasoning (CBdR).

In this section, applications and principles of CBdR research are reviewed to establish principles on which the validity of a new case-based redesign-reasoning model can be tested. Particular emphasis is given to the building design domain, as this is most closely related to the domain of redesign for people with disabilities. The attraction of CBdR as a methodology lies in the close correspondence between case-based human learning and computational CBdR. Both involve linking new problems to previous cases. CBdR thus matches our current understanding of how students learn building design (Schön, 1991a).

In the example of applying the CBdR methodology to design a house, a previous similar house design problem is recalled and then solution adaptation enables a fit to the new design situation. Major considerations are recall of previous experience and deciding what features require adaptation and which should stay the same (Maher et al., 1995). Case-based building design research currently focuses on technical issues of case representation, presentation, retrieval and adaptation, with some attention to social issues and usability (Watson & Perera, 1997a).

Research into CBR for building design in particular has been characterised by several recurring issues relevant to implementation of CBdR systems (Macedo & Cardoso, 1998; Maher & Gómez de Silva Garza, 1997; Schmitt, Dave, & Shih, 1997).

These are summarised as follows:

- ▶ size and complexity of cases — composition, spatial, temporal and causal relationships all require generalised design domain knowledge;
- ▶ formalisation of ill-structured bodies of knowledge; and
- ▶ the need for various modes of representation (e.g. text, graphs, equations and drawings).

3.4.1 CBdR product representational model

Representation in case-based design systems means the “form in which the case is stored in the computer as part of a case-base” (Maher et al., 1995, p. 84). Cases in case libraries need to be concrete implementations of complex information (Kolodner, 1996). This implies some level of case-data abstraction. Encoding of salient case elements enhances the uniformity, understandability and navigation of case structure for computational purposes.

Representational formalisms derive from computational research and development. Wide ranges of formalisms exist (e.g., attribute-value (A-V) feature pairs, frames, graphs, trees, networks, rules and qualitative models) and are used for storing case-based design application data in machine-readable form. Cases can be represented using a variety of formalisms. Some of these formalisms are easier for human users to understand than others.

Uniformity is most simply and commonly achieved by structuring input-problems, case contents and solution subparts into a set of *attribute-value (A-V) feature pairs*. Defining the attributes constitutes a significant part of the ontological structure of the domain knowledge. The use of A-V feature pairs follows from object-oriented and database management views of design (Maher et al., 1995).

Frames are a type of object-oriented representation that uses A-V feature pairs to describe design objects. Object-oriented representation extends representational power by organising objects into *classes*, a special type of taxonomy or grouping for objects that have similar properties and methods. Additionally, the greater formalisation improves flexibility by enabling hierarchical inheritance. Hierarchical inheritance of features in object-oriented representations deals with abstraction levels by grouping object classes hierarchically. Class hierarchies also work to support decomposition and recomposition of cases.

Graphs and trees require consideration of the knowledge being represented by each node and link (Maher et al., 1995). Some case-based design applications use graph structures to represent complex compositional case knowledge by organisation of cases into concept hierarchies. However, recall based on graph matching can be problematic because algorithms must be mathematically computable (Qian & Gero, 1992).

Other knowledge representation techniques, including *rules and qualitative models*, are traditional artificial intelligence techniques that require well-structured and explicit domain knowledge to be formalised. Advantages lie in enhancing automation of reasoning abilities, but implementation increases system complexity. However, when domain knowledge is weak, poorly understood or ill-structured, implementing these techniques becomes impossible.

Developing CBdR systems presents several challenges because design problems in the real world are large, complex, and require multiple modes of representation (Gebhardt, Voss, Grather, & Schmidt-Belz, 1997). Moreover, mapping from problem to solution in design is context-dependent and is therefore difficult to define *a priori*. In fact, finding a solution often means merging many bits from prior cases. Case-Based building design research currently focuses on the representational issues of case presentation, retrieval and adaptation with some attention to social issues and usability (Watson, 1996).

Design usually involves graphics and design documentation. It increasingly uses computer technologies for this output. The dependence on technology of modern design production means that computational storage, decision support, computer aided drafting and multimedia graphical visualisation formats are fast becoming the norm in building design. The graphical aspects support visualisation and enable designers, who are primarily graphically oriented, to interact and recall visual content.

Typically, capturing of design domain knowledge for CBdR systems combines both human and computer readable data. Data types include those outlined by Simoff and Maher (1998c), and are detailed in Table 3.1.

Table 3.1: Variety of design data relevant to design reasoning

Data types	Examples
Unstructured	Bitmaps i.e. scanned or copied images, raster images of photographs & sketches, audio, animations and video etc.
Weakly structured data	Free text, spreadsheets and tables, 2-D & 3-D object-oriented images, hypermedia links etc.
Strongly structured data	Attribute-value pairs, relational tables, object-oriented structures etc.

Consequently, current design information systems span a variety of computational media and include multimedia formats as illustrated in Figure 3.6.

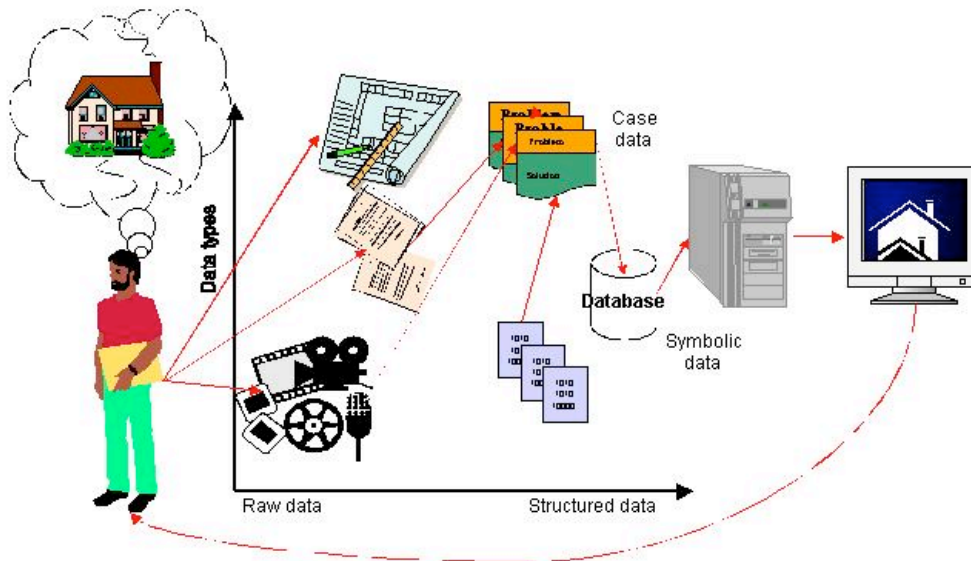


Figure 3.6: Representational media used in design information systems

Furthermore, computational media such as the Internet and the Web have opened up previously unseen opportunities for collaborative development and distributed case-storage. New systems for case navigation are beginning to play a major role in popular computing. Theoretical issues in navigational systems currently share a high level of overlap with key issues in case-based design. For instance, navigation of cases or case knowledge overlaps with case recall and implementation of specific strategies such as indexing, searching and browsing. In applying case-based techniques to design, the fact that design starts with a concept and then becomes more specific means that initial problem descriptions can be ambiguous, incomplete, contradictory and unconstrained. On the other hand, commencing with a concept that is highly abstract in nature has the benefit of reducing complexity by reducing the number of features, and constraints under initial consideration (Bergmann & Wilke, 1996; Richter, 1998). Figure 3.7 illustrates this idea and indicates the importance of refinement as a means of achieving concrete product descriptions in design activities.

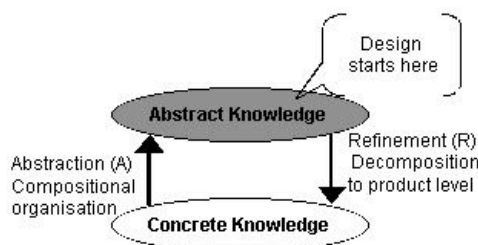


Figure 3.7: Problem solving in design starts with abstraction

Distinguishing abstraction levels is critical to decisions about computer readability (representation) and decision support for humans (presentation). Due to computer readability issues, Bergmann and Wilke (1996) differentiate between abstract cases, concrete cases and

hierarchical cases. Several concrete cases usually correspond to a single abstract case or prototypical representation. However, concrete cases typically differ in detail only. An alternative is a hierarchical case structure, which contains information at several levels of abstraction. As previously discussed in chapter two, this fits with current understandings of design reasoning where a designer explores a hierarchical case by making design *moves* from high levels of abstraction, through the various design task stages, to levels of concrete detail. Schön (1991b) believes that assumptions made by designers as a reaction to the inherent complexity in the potential design space accounts for many of the unintended consequences that are typical of the design process. So, while hierarchical cases can help simplify the process of design decision-making, they fail to reduce or adequately cope with redesign.

3.4.2 CBdR task-method process representational model

A task-method model of CBdR has three main elements: tasks, methods and knowledge (Goel & Murdock, 1996). These are elaborated on as follows:

Tasks the act of designing commences with input in the form of a design problem. Typically this is the functional specification required of an artefact and output is the specification of the structure of the artefact that can fulfil the input parameters. Approaches to the basic design task will spawn new, more specific, design problems and subtasks.

Methods are characterised by the subtasks and control functions. As previously discussed and illustrated in Figure 3.3, the generic subtasks of a CBdR include recall and adapt.

Knowledge in a CBdR is held within cases. Knowledge is therefore contextual and is characterised by its content, by its form of representational languages, and by its organisation and storage. As illustrated in Figure 3.8, case-based knowledge is typically stored and accessed from a database or case library. The new design requirement prompts case-based recall e.g., big arrow from the case library. After recall, the case may be adapted and then the new design solution is stored e.g., big arrow to the case library.

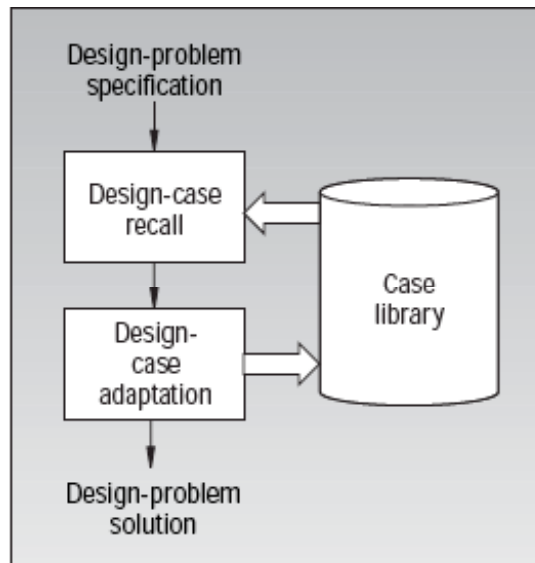


Figure 3.8: A generic CBdR process model (Maher & Gómez de Silva Garza, 1997, p. 35)

There are already a number of CBdR systems in the building domain and each of these approaches tasks, methods and knowledge differently. Understanding similarities and differences relevant to selecting an approach for a redesign system requires a review of the basic components and then examination of how different CBdR systems have implemented these ideas. Currently CBdR can be compared by design application type, i.e. architectural, structural and physical devices.

Architectural CBdR applications include ARCHIE-2 (Domeshek & Kolodner, 1997), CADRE (Hua, Schmitt, & Faltings, 1992), SEED (Coyne, Flemming, Piela, & Woodbury, 1993), FABEL (Coulin, Grather, Linowski, & Schaaf, 1994) and GENCAD (Gómez de Silva Garza & Maher, 1999a). There are also a number of CBdR systems for the more narrowly defined *structural design domain*. These include CADSYN (Maher & Zhang, 1993), CASECAD (Maher & Balachandran, 1994) and SAM (Maher, 1997). The three systems concerned with structural engineering are fairly concrete, with quite well structured domain knowledge, but the others are more general. A more general CBdR system for designing *physical devices* exists and is known as KRITIK3 (Goel & Murdock, 1996). KRITIK is the only CBdR system to explicitly discuss redesign. In KRITIK, redesign is part of the adaptation task dealt with as blame assignment (Stroulia, Shankar, & Goel, 1992). Blame assignment relies on diagnostic reasoning to resolve adaptation problems. A closer examination of these systems in relation to key representational issues follows. Table 3.2 summarises their task-method models.

Table 3.2: Design case task-method comparison by system

System and task components	Task input & output	AI methods employed
ARCHIE-2 (browse, search)	Architectural design goals, plans and outcomes	User directed browsing & navigation, knowledge representation of qualitative models
CADRE (select, constrain, adapt)	Attribute-value pairs for building architectural components, two dimensional CAD configuration of spaces	Constraint satisfaction, Sub-case combination, attribute-value matching, dimensional & topological adaptation
SEED (specification, generation, evaluation)	Attribute-value pairs for building architectural components, three dimensional CAD configuration of spaces	Sub-case combination, design plan replay, hierarchical problem specification matching, attribute-value matching
FABEL (sub-goaler, browser, designer)	Matching of graphs, feature vectors, bitmaps, predefined & dynamic gestalts, and features relevant to graphical reasoning for architectural design	Generate & test, graph matching, attribute-value matching, image & gestalt based pattern matching
GENCAD (select, combine, modify, evaluate)	Function, behaviour & structure variables for spatial composition of buildings	Genetic algorithm
CADSYN (retrieve, select, decompose, adapt, combine, update)	Function, behaviour & structure variables for structural engineering of buildings	Constraint satisfaction, subcase combination, attribute-value matching
CASECAD (browse, edit, retrieve, select, draw)	Function, behaviour & structure variables for structural engineering of buildings	User directed browsing & navigation, attribute-value matching
SAM (browse, search, build)	Function, behaviour & structure variables for structural engineering of buildings	User directed browsing & navigation attribute-value matching
KRITIK3 (elaboration, retrieval, adaptation, storage)	Structure, behaviour & function variables for physical devices	Computation of functional difference, diagnosis & repair, model revision & model verification, heuristics, discrimination tree search & reorganisation, functional indexing

Note. The synthesis of material presented stems from independent analysis of the CBR programs reviewed.

Many different approaches are evident in these nine systems. While all nine systems have some form of case-based retrieval function only the multimedia systems like SAM, ARCHIE-2 and CASECAD offer case-based browsing. SAM has limited autonomous reasoning functions offering only human directed browsing. In other words, all the other systems with autonomous reasoning functions achieve this by drawing on additional non-case-based knowledge (i.e. typically knowledge encoded as a set of 'if X then Y' type rules) that are not stored with or attached to case data.

Methods for case-based design adaptation are evident in most applications but are much less significant in terms of computational effort in the more recent multimedia systems where emphasis instead focuses on facilitating human user interaction to solve the adaptation task.

Not all building design applications provide an overall process model. Instead, some deal with each design task independently (e.g., FABEL), and in others control and data flow are controlled by the user not the system (e.g., SAM and ARCHIE-2). It is clear that computational and human user approaches are not mutually exclusive and that many systems typically combine approaches depending on the domain, view or perspective required. Figure 3.9 provides a visual illustration of some of the similarities and differences between three of the CBdR systems that have task-method models with explicit control and data flows. For instance, KRITIK3 when compared to CASECAD and CADSYN (as shown in Figure 3.9) includes process knowledge in the form of task-method models. Part of its adaptation reasoning addresses the subtask of model revision and verification (Goel & Murdock, 1996 p. 153).

Figure 3.9 illustrates both differences (e.g., schematic layout) and similarities (e.g., centrality of retrieval mechanism) across three systems. Many complex reasons underlie the differences in approach evident when comparing computational systems. Approach depends on purposes and capabilities of the system designers and the exact knowledge domain being addressed. For this reason, further analysis of this type of difference remains difficult and unproductive. Alternatively, commonalities associated with best practice in representation, recall and adaptation options are further analysed in regard to their suitability for a case-based *redesign* reasoning application (CBrR).

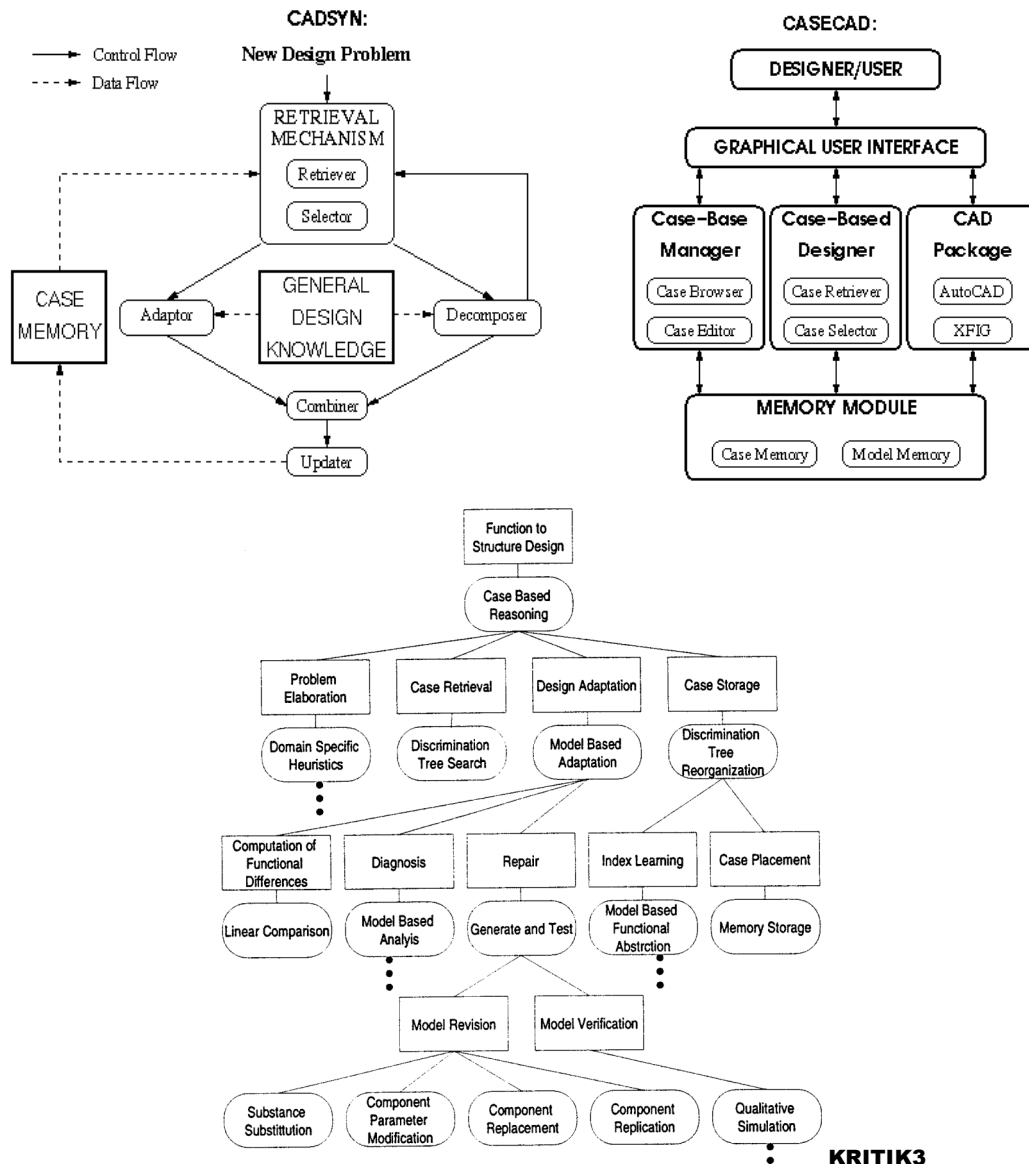


Figure 3.9: A comparison of the case-based tasks and methods employed in CADSYN (Maher et al., 1995, p. 144); CASECAD (Maher et al., 1995, p. 167); and KRITIK3 (Goel & Murdock, 1996, p. 155)

3.4.3 Case formalisation, representation and presentation in CBdR

An understanding of the case representation and presentation approaches used in building design provides a foundation for implementation of a redesign case representation schema since reasoning in redesign concerns building design components. As knowledge is primarily contained in cases in CBdR systems, representation of cases is fundamental.

In architectural and building design, cases are complex. A design case may involve multidisciplinary collaboration, may develop over a long time, and generally involves multiple forms of data. Cases may vary widely in size, from the isolated toilet block to the multi-storey building or shopping complex with millions of components. Thus, central questions in any CBdR system are what knowledge gets computationally encoded and

whether the knowledge requires partitioning. If partitioning or encoding is required then the developer must consider how this might be accomplished. In other words, the representational model in a CBdR system determines both case-description and case-retrieval. Successful presentation, on the other hand, concerns the act of showing or revealing something usually to the end user and what can be inferred or manipulated by humans naturally rests on prior decisions regarding the computational languages and formalisms employed plus meaningfulness, scope and concreteness of the media and semantics used. Together, representation and presentation provide significant ontological knowledge in the form of terminology, case structure and definition of permissible values and secondary features (Gebhardt et al., 1997).

3.4.4 Recall in CBdR

Design problems are complex, so a CBdR system must respond to this appropriately by applying good strategies for recalling cases. Voss (1996) characterises ‘good strategies’ as those which support but are distinct from case-based processes and which can deal with issues surrounding problem decomposition, multi-case retrieval and case combination. In Voss’s framework, three key nodes must be present: a problem description or input case (P), plus a number of source cases that are organised in some fashion (C) and which contain a solution component (S). In this system, data flow between nodes can be graphed and node relationships are defined by cardinality i.e. 1:1 or 1:N, etc. Figure 3.10 illustrates how decomposition, recomposition and iteration strategies can be applied to case-based processes, including recall and retrieval. Selection of strategy is closely coupled to the organisation of the cases within the case library, but the relationship is not one to one.

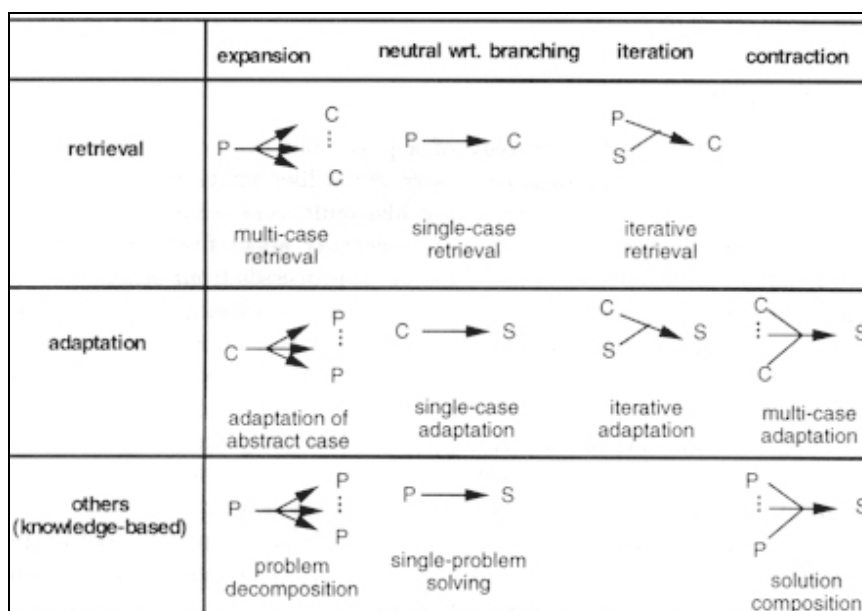


Figure 3.10: Potential constituents of strategies for CBR (Voss, 1996, p. 434)

CBdR recall can be primarily viewed as a pattern-matching problem where features are represented as a set of attribute-value pairs or as a network of attributes (Maher et al., 1995). Recalling design cases requires consideration of guided user navigation and browsing, plus attention to computational implementation of indexing, search and retrieval and selection strategies.

3.4.4.1 Navigation of case memory

Navigation relies on case representation and is limited to case-parts formalised within a particular case-based application. Knowledge navigation has become an issue for web-based utilities and has become an increasingly important issue for web-based CBdR systems (Hammond, Burke, & Schmitt, 1996). Web-based CBdR systems are essentially hypermedia systems where information is segmented into pages. Cases in a web-based system are typically a set of files written in HTML (Hypertext Markup Language). HTML allows the user to browse case content using hyperlinks. In a basic hypermedia system, the user navigates information spaces by following embedded links that contain Uniform Resource Locators (URLs). The idea of *movement* through information spaces is central to the concept of navigation (Cunliffe, Taylor, & Tudhope, 1997). Figure 3.11 illustrates the implicit hierarchical structure of URLs. Creating a Website involves grouping web-pages into clusters so that each cluster has an implicit meaning and contains pages that are somehow related (Jaczynski & Trousse, 1998).

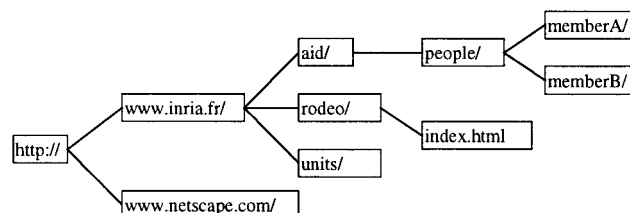


Figure 3.11: Hierarchical structure cluster of web-page URLs (Jaczynski & Trousse, 1998 p. 168)

However, lack of transparency and other navigation aids can result in the user reaching a dead end or becoming lost in hyperspace (Micarelli & Sciarrone, 1996). Case-based knowledge navigation implies that the case-based system designer has responsibility for charting the course of discovery so that the user does not get lost and the case-based system responds to their needs. Charting a course through a case-based system means helping the user find solutions to fit their needs in a space where there are many choices. The use of familiar icons, metaphors, information layout, navigation bars and ensuring consistency in layout and information presentation can facilitate navigation. Navigational aids should impose a structure

on the web page, case or case-part being examined to make it easier for the user to see; (1) items of relevance; (2) related items; (3) more/less detail.

Navigation has primarily been a research area for Information Retrieval (IR) but has become increasingly important for web-based CBdR systems such as SAM. SAM provides a number of navigational aids on each page to let users see where they are in the system, what information is available to them, and how to access more information. Anticipating user needs and adequately representing them determines the usability of a case base. Users typically navigate a case-base by browsing cases directly or by selecting salient aspects of the new problem scenario to search the case memory for the closest match. A closer examination of specific browsing and search strategies follows.

3.4.4.2 Browsing

Primarily case-based design aiding systems usually support some form of case browsing. Browsing allows the user to explore the case library in an unstructured way. However, random browsing is often unproductive. Useful browsing systems usually impose some sort of structure so cases can be viewed according to some common thread or grouping (Kolodner, 1993). For instance, ARCHIE-2 groups schematic floorplans by building type and annotates these according to architectural issues. The additional structure facilitates browsing of the floorplans and allows the user to select a case by title or by issue. CASECAD's structure also permits browsing in both symbolic and graphic modes, but users need to swap between modes, as integration of modes, was not a key objective.

Most current concepts about structuring information stem from the organisation of books, journals, indexing and cataloguing systems. Useful metaphors borrowed from book structure and applied to case-based browsing include familiar metaphors like *table of contents* and *book index* (Kolodner, 1993). ARCHIE-2 uses the *book index* metaphor to present users with a menu of navigation options. SAM uses the *table of contents* metaphor to make explicit the contents of a whole case and the underlying case structure.

Hypermedia links do not require hierarchical navigation, so SAM communicates hierarchical organisation to the user by utilisation of case-part icons that are layered to indicate movement from the general to the specific but which are not networked by lines. Networking by lines in this case could unintentionally prompt users to browse in a hierarchical fashion. Figure 3.12 illustrates some of the navigational features that guide users when browsing SAM's cases. The illustration on the top shows a typical front page in SAM in which 'scrolls' act as hyperlinks and assist the user to get help or return to the SAM home page, and which also make explicit the underlying hierarchical organisation of case data. In the illustration on the bottom, a different case shows a lower more concrete knowledge level.

Links in hypermedia organisation structures are central to guided navigation. Recent usability testing indicates that the success of a link depends on how well the user can predict where the link will lead and how well the user can differentiate one link from other nearby links. It also appears that a negative correlation exists between the number of choices and user success (Spool, Scanlon, Schroeder, Snyder, & DeAngelo, 1997).

Grosvenor Place

Contents of this page
 Project Data
 Requirements
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Front Page
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Netscape: Vertical Load Resisting System

load transfer strategy

The building is rectangular in plan with the shorter dimension being 67.3 m. The strategy implemented by the primary structural system is to transfer the vertical loads in the direction of the shorter dimension, and hence over the shorter span for the building. The loads that reach the western edge are then collected and transferred vertically down to the foundation at five locations. The loads that reach the eastern edge are collected and transferred horizontally over a span of 138.5 m and then transferred down to the foundation at two locations.

load path

The loads applied to the secondary structural system of the roof are transferred to the arch members of the diagrid as a series of concentrated loads approximately 600 mm apart, the spacing of the purlins which form the part of the secondary system that is in direct contact with the diagrid arches. The load paths and load flow pattern, through the structure, due to a typical concentrated load depends on the stiffness distribution that exists in the structural arrangement. The 1 m deep stiffening trussed arches with direct connection to the buttresses being the stiffer elements would tend to attract more of the load than v-shaped trusses spanning 25 m between the buttresses. A typical load path would thus be first along the arch, on which the load is applied, the load path would then branch out along the arches that intersect this arch and the loads would find their way to the stiffening trussed arch and the v-shaped truss, from there the loads will flow towards the buttresses on the western edge and towards the light supporting trusses on the eastern edge. The buttresses provide vertical downward load paths to the foundation. The light trusses, on the western edge provide upward load path to the transfer arch, from where the load path follows the arch to the foundation.

Images courtesy of Connell Wagner, Sydney.

Figure 3.12: Hypermedia navigation browsing in SAM (Maher, 1997 p. 5 & 6.)

In general, the more links, the more likely the user is to get lost. In addition, Spool et al. (1997) found a weak positive correlation with image links, meaning that images, especially linked to text descriptions, were helpful for user navigation.

The decision to implement multiple retrieval modules in both SEED and FABEL was based on the premise that users require multiple pathways into case-data depending on the reasoning task and stage. Site navigation maps provide a tree diagram of the web site that users can use for point and click exploration. Users can quickly locate any web page without having to traverse links or enter query strings (Hughes, 1997). In this thesis, it is assumed that multiple browsing strategies including provision of a site navigation map and graphical summarisation of case contents assists reuse.

3.4.4.3 Search

Search has been distinguished from browsing by being more directed, goal driven and planned (Cunnliffe et al., 1997). Search as a strategy requires development of a computational search strategy to traverse a case-base in order to locate relevant cases or case-parts. Search facilitates the recall and reuse of cases in case-based systems by mapping between the input query, or description space, and the solution spaces in cases contained within the case base. Search ends when a best matching previous case or case-part is retrieved. The more complex and hierarchically structured case representations are, the more explicit the relations need to be between case description and case solution features. Mapping knowledge correlates groups of description features with solution features. Figure 3.13 illustrates this mapping of knowledge between spaces.

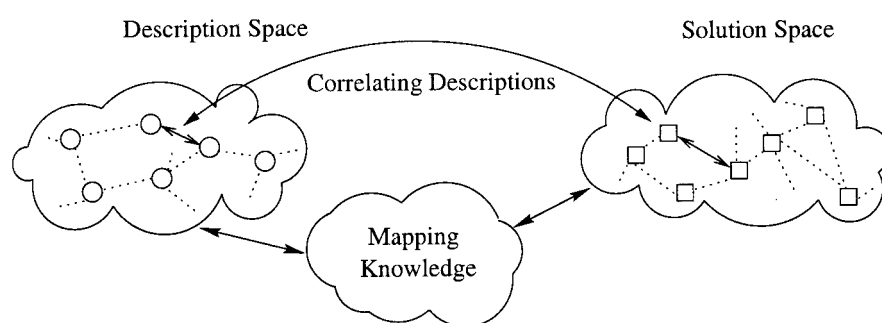


Figure 3.13: Mapping between description and solution spaces
(Wilke, Smyth, & Cunningham, 1998, p. 135)

The knowledge process of search encompasses computational methods such as index matching, retrieval and selection, all of which are essential to CBdR.

3.4.4.4 Index matching

Indexing has to identify attributes that may be relevant in as-yet unspecified future problems. The indexing issue partly concerns the development of uniform terminology for items that might appear in different cases under different names. For example, handrails and grabrails have some overlapping features and purpose but are generally differentiated by size and location. Nevertheless information about fixings in a particular context may be relevant despite terminological differences.

The indexing task proceeds by dynamic computational generation or by *a priori* hand coding. Unless a case-based system has a means of assigning labels to case features, it cannot search cases or case memory for matching attributes. Assigning labels requires the definition of a domain relevant vocabulary or ontology. Developing an indexing vocabulary means identifying all relevant object features, concepts, and relationships for a particular domain (Maher et al., 1995). Figure 3.14 illustrates a simple list-based indexing scheme where indexing is based on a vocabulary of features or sets of features. Unfortunately, list structures may be insufficient for anything other than feature-based matching. A fixed set of indexing features may only accomplish surface-based matching thus overlooking cases that might be relevant at a more abstract level.

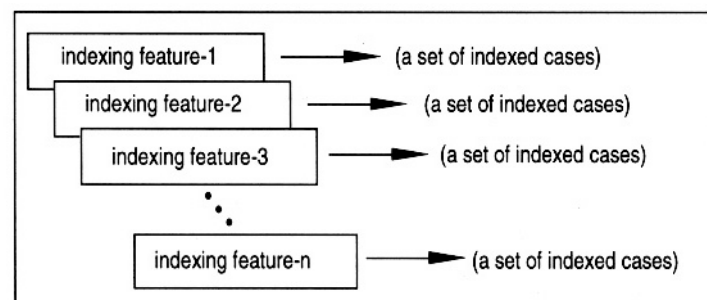


Figure 3.14: A list-based representation of an indexing system (Maher et al., 1995 p. 89)

In a list structure, a set of pointers to cases are stored under the relevant indexing feature, but in a tree-like structure, features are arranged hierarchically by some sort of clustering mechanism or model. Greater flexibility in matching requires an indexing scheme that can capture relations that are more abstract. A tree structure enables indexes to cases to be stored as a part of an abstraction hierarchy. Figure 3.15 illustrates this kind of indexing structure.

During retrieval, a hierarchy is traversed in a top-down fashion. Domain knowledge can be used effectively to achieve this. For instance, in CASECAD and CADSYN, the classification structure used within cases provided a means of clustering both categories and attributes of design cases. A classification structure or ontology enables decomposition of complex cases into subcases. Abstraction hierarchies in indexing not only improve flexibility but also make

retrieval more efficient by only searching relevant partitions in the case-base system (Maher et al., 1995).

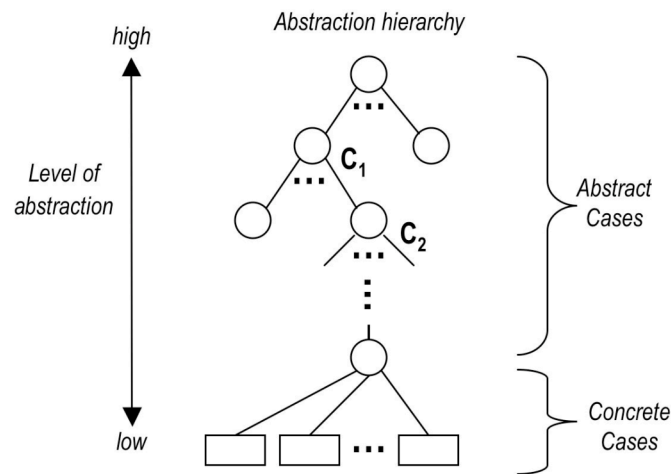


Figure 3.15: Abstraction hierarchy for indexing cases (Bergmann & Wilke, 1996, p 32)

However, for indexing by abstraction hierarchies to be effective, input queries must match abstraction levels. The issues involved in matching input require that cases and case parts be labelled so that useful and efficient access is possible (Kolodner, 1993). Moreover, in an aiding system, close correspondence between the indexing vocabulary and users' conceptions of their domain and task helps (Griffith & Domeshek, 1996). In the context of aiding systems, the indexing problem becomes a human-computer interface issue. Difficulty in selecting meaningful labels and capturing salient differences between cases makes case indexing difficult. In this thesis, meaningful labels are generated based on the redesign model terminology and segmentation structures.

Indexing has been covered extensively because it is central to ontology development and representation of case contents. Indexing lays the foundations for domain matching, recall and reuse. In this thesis for these reasons, abstraction hierarchies based on domain relevant semantics and vocabulary are central to ontology development purposes,

3.4.4.5 Case retrieval

Retrieval means to find again or extract stored information from a case base. Retrieval in CBR is the computational process of searching cases or case libraries to identify which cases have all or a subset of those attributes which should be retrieved for further consideration (Maher et al., 1995). Computational retrieval techniques rely on an application of a similarity metric of some kind.

A review of commercially available CBR development tools (e.g., ReMind, CBR-2, KATE, ReCALL) identified *nearest neighbour match*, a similarity metric based on pattern matching, as the major methodology (Watson, 1996). Although this methodology is both simple and fast, it is not always accurate. Accuracy can vary because the context determines importance in some reasoning tasks. Assessing a case only on values derived from an evaluation function does not always equate with the importance of a retrieved case-based solution in the new context. Anyone who has used a web-based search engine or online library catalogue knows the problems likely to be encountered using search terms that are either too specific or too broad. For instance, if searching for ‘rail’ in the context of wanting information about handrails and/or grabrail fixings the ‘rail’ retrieval function could easily return a significant amount of unwanted material such as rails pertaining to trains. Therefore, retrieval based solely on nearest neighbour matching often fails to select useful cases (Kolodner, 1993). In this thesis, selection of cases requires combining nearest neighbour matching with other knowledge-based techniques such as segmenting and prioritising case memory and allowing users to set importance criteria for query cases.

3.4.4.6 Case selection

Selection is about choosing the best or most suitable case for the new design problem. More specifically, selection in a case-based design system is the process that ranks and chooses one particular case for the new problem (Maher et al., 1995). It is often difficult to narrow down the choice to a single case or case-part. Multiple matches make comparison of similarity more difficult. When two or more matches occur, decisions have to be made about which case to select. At the most simplistic level, in a case aiding system, the user can rank and/or choose to reuse cases or case parts based on individual examination of all cases returned by the retrieval algorithm. In more automated systems, the most common approach is to select one of three basic computational methods for determining relative importance. The three basic methods are statistical, analytical and precedent-based.

Statistical and analytical approaches use initial input parameters to retrieve a relevant model-based or context independent representation. Unfortunately this approach requires well-defined models and can be difficult to implement when solutions are the result of sub case or case-part combinations (Ashley, 1989). Index revision, on the other hand, is an *iterative search strategy* (i.e. a search strategy where features are elaborated and refined in a cyclic fashion during the search process). Index revision uses actual cases (i.e. precedent-based search techniques) rather than abstract models to refine input specifications. Index revision has been defined as the “process of changing the initial specifications by searching case memory” (Maher et al., 1995, p. 106).

In CASECAD the initial query depends on feature selection based on its model, but retrieval of a case by matching only a part of its model results in low reusability and requires greater feature transformation. However, if a search is iterative, recalling relevant parts from other cases may reduce some of the transformation burden. Iterative retrieval appears to be particularly helpful in the conceptual design phase where the user may not have considered all pertinent alternatives. Index revision may also be helpful in retrieval of alternative cases when one case is insufficient to provide a complete case solution and the user needs to select additional case-parts from other cases.

3.4.5 Adaptation in CBdR

Case adaptation concerns the computational strategies implemented to make changes to cases to fit them to the new context. Discerning what needs changing and accomplishing this make adaptation a difficult computational task (Maher et al., 1995). For most CBR systems, especially those in the commercial domain, adaptation is generally limited to simple actions such as *parameter adjustment* (i.e. a computational algorithm is applied to adjust numerical parameters using domain knowledge of allowable degrees of freedom) or simple *value substitution* (i.e. replacing one value with another). CBdR systems like CADRE apply domain knowledge in the form of rules for parameter adjustment to change the values that describe the geometry of a previous design case. Simple adaptation actions generally work well with concrete cases where descriptive features and solutions have a simple atomic relationship and domain knowledge can be formalised.

However, hierarchical representation increases adaptation complexity because differing levels of abstraction require different adaptation techniques. For instance, adaptation of abstract case structures requires a complex operator that can match the appropriate adaptation action to the abstraction level. This type of adaptation operation uses configuration knowledge derived from uniform representation structures that are decomposable. For instance, KRITIK2 uses its uniform case representation format to enable functional mapping between description and solution spaces in cases, in order to preserve relationships among function, structure and behaviour of devices (Stroulia et al., 1992). Nevertheless, Wilke et al. (1998), who also propose this technique, warn that the configuration approach to adaptation requires straightforward mapping between description and solution spaces. Figure 3.16 illustrates how a complex operator sequences any complex actions in a downward direction, moving from abstract to concrete levels.

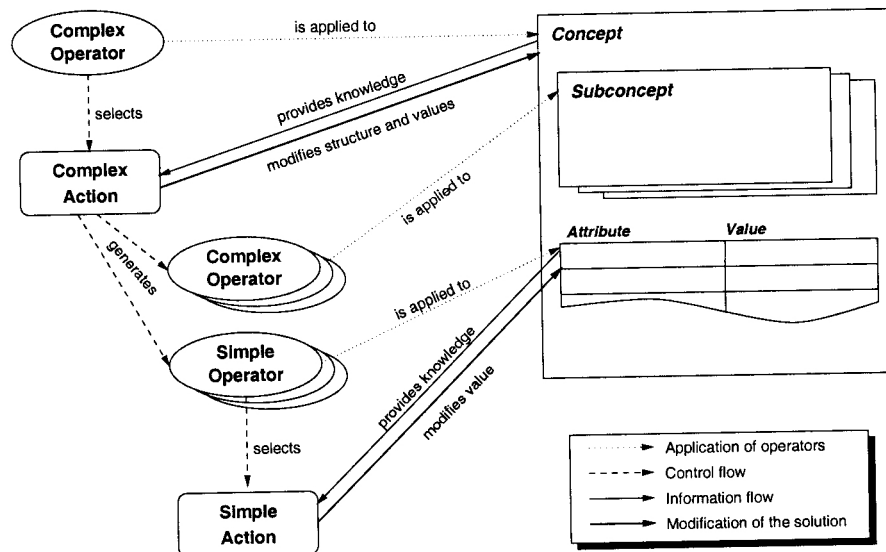


Figure 3.16: A general idea of how adaptation operators work (Wilke et al., 1998, p. 156)

In theory, analogical techniques that transform or derive adaptation knowledge provide an alternative means of more innovative case-based adaptation (Kolodner, 1993). However, implementation of case adaptation using such knowledge-driven techniques depends on articulation of domain knowledge, and this varies substantially from context to context, making analogical generalisation across contexts almost impossible. For example, in PRODIGY (a derivational analogy reasoner), the derivational trace records the sequence of decisions taken. However this only works where autonomous reasoning occurs and is difficult in domains where a causal domain theory cannot be clearly computationally articulated (Carbonell 1986).

Computational adaptation strategies also require consideration of domain-related constraint satisfaction issues, including evaluation and repair of solutions to ensure fitness. For this reason, primarily case-aiding systems leave adaptation entirely up to their users. Redesign, as a related but different activity, further complicates exploration of computational adaptation. As the research emphasis in this thesis concerns case representation and recall, implications for redesign case adaptation are touched on but not developed at length. Instead, as in other case-based design aiding systems, like SAM and ARCHIE-2, it is assumed that adaptation will be primarily human user directed and thus not automated.

3.4.6 Accumulating experience or learning in CBdR

Case-based systems, like human experts, acquire knowledge over time as their case-base is extended. Every time a case is added to the case-base, the reuse options are enriched. In this sense, learning is an emergent property of case-based systems, supported by the structuring and/organisation of all the component parts (Kolodner, 1993). However, for learning to occur, cases must be added to the case-base and appropriately indexed so they can be recalled

effectively in the future. Cases stored in the case-memory represent what can be recalled, or the range of relevant experience. Generally, the greater the diversity of cases within a case library, the less adaptation will be required, because the likelihood of recalling a relevant case increases proportionally. The power of case-based systems resides in having relevant cases available for reuse.

3.4.7 Case acquisition

Case acquisition is the process task of acquiring new cases. The most natural way to acquire new cases involves storing the input query and its solution as a new case within the case-base. But case addition requires uniformity and regularity of knowledge. CASECAD, CADSYN, CADRE, FABEL and SEED all require that the case-base or case library be stocked or *seeded*. This means hand encoding a representative sample of cases. Only after sufficient representative cases are available for adaptation purposes can these systems acquire the transformations as new cases automatically. Hand encoding computationally relevant data by the system designer generally ensures that case-data is presented and segmented in a uniform way and avoids the issue of having to ensure that data entered by users' works within the search and storage techniques employed.

The structure of a case provides information that integrates components. In other words, the case structure contains information that can be reused during case acquisition to ensure uniformity and regularity in case representation. Lack of uniformity and issues with case indexing are evident in SAM, where hand encoding was used for initial seeding of exemplar cases and then students added cases as part of their coursework. In the case of SAM student hand encoding of HTML pages resulted in loss of uniformity with consequent impact on computational retrieval and search functions. However, it also made it more difficult for human users to extract relevant information. The redesign model presented in this thesis aims to make its case structure overt to allow automatic case acquisition and indexing, reducing hand-coding and facilitating extension of its case-base.

3.4.8 Index representation

For computational purposes, indices are usually stored as lists or in decision tree like structures, both of which have already been presented in section 3.4.4.4. However, learning requires that indices be updated to reflect new features whenever a new case is added to the case library. An alternative to manually encoding indexing features involves dynamic generation of indices. For example, RICAD, a risk cost adviser, achieves dynamic indexing by using heuristic rules to identify all significant attributes and appropriate range values. These dynamically generated features become the indices that are used to retrieve relevant cases (Daengdej, Lukose, Tsui, Beinat, & Prophet, 1996).

Dynamically generating indices becomes attractive when the relevance of attributes depends on retrieval contexts. In this thesis, dynamic generation of indices involves clustering of features based on the redesign representational and ontological model developed in chapters four, five, six and seven.

3.5 Case-based building design

Building design differs from design in general in that a complete design description includes the buildings' elements and their relationships. However, there is typically no direct link between structure and function; the relationship is implicit and is mediated by expected behaviours of materials. For instance, choice of window type, position, opening size and glazing all relate to the light flux transmitted, the ventilation rate and the various solar gains. Certain choices and combinations of building elements determine how particular functional outcomes are created, maintained, prevented or controlled (Chandrasekaran, Goel & Iwasaki, 1993).

Additionally, structures for architects are primarily about manipulations of space and include the consideration of points, lines and planes that enclose and define spaces in terms of volume or quantity. This attention to structure in terms of substance, shape, size, colour and texture provide the spatial experience and spatial qualities. For instance, two points such as vertical columns serve to define an entry or gateway (Ching & Adams, 1996).

Moreover, both Alexander (1979) and Rapoport (1969) believe that mental models (i.e. habit based pattern languages) form the traditional tools of building construction. Many construction problems and solutions arise because of issues encountered during construction that were not fully anticipated in the design phase. The more modular and prefabricated the components and/or the more irregular the contours of the site, the more the builder must adapt the design representation during construction.

Drawings are representative and as such present an abstract ideal, which may not accurately map out the level of actual construction detail needed. For instance, failure to specify the fall of the floor in the bathroom, the angle of approach of a ramp, or the length of the level area required for a parking bay, may result in construction outcomes which are less than desired (Bridge, 1999).

3.5.1 Representation of building design cases

The basic partitioning of design cases involves, at a minimum, the original design problem and the output or the final solution. Representation of cases through these two simple data sets appears to work well in several commercial applications such as diagnosis or help desk

applications. However, where tens of thousands of objects may be involved in cases (as the building design domain), a more sophisticated approach is needed (Gebhardt et al., 1997).

Representing different views or levels as separate cases, or breaking a design episode down into constituent pieces, present means of managing building design case complexity more efficiently (Watson & Perera, 1997b) but raise another set of representational challenges to do with context and composition. In building design, many constituent parts can only be understood in terms of connections and adjacency (Faltings & Hua, 1991). These issues mean that new design problem queries may not neatly fit source cases so that resolving matching, extraction and adaptation strategies also involves more complexity (Gebhardt et al., 1997).

Decisions must also be made about whether to attempt data extraction from large database models, such as those contained in computer aided drafting (CAD) presentations, and what the boundaries for a useful case might be in terms of content. For instance, should the main unit of representation be a room, a floor or a whole building? Choices about unit of representation in systems such as GENCAD include the use of levels of abstraction. GENCAD describes its cases at three distinct levels: the landscape, house and room levels. A diagrammatic example of representation at these three levels is shown in Figure 3.17. Within levels, objects are represented by lists using attributes and their associated values (Gómez de Silva Garza & Maher, 1999b).

Resolving potential complexities makes selection and attention to data abstraction structures particularly critical in the building domain area. Schmitt et al., (1997) reinforces this point when they say, “building designs involve multiple abstractions; for example, architectural, structural and mechanical” (p. 249).

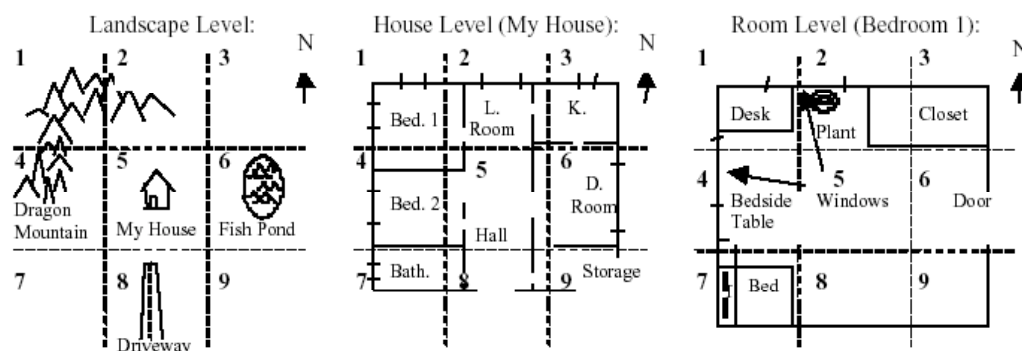


Figure 3.17: Three levels of residential description used in GENCAD (Gómez de Silva Garza & Maher, 1999b, p. 5)

The level of abstraction chosen for case representation depends first on who or what will be reusing the information. The underlying issue is one of automation versus human

understanding. All case-based building systems require user input to evaluate and rank suitable cases. Some are designed primarily as case-based design aiding systems (e.g., ARCHIE-2 and SAM) and others are designed for more automated reasoning functions (e.g., the adaptation functions in CADSYN and CADRE). Although ARCHIE-2 and SAM can both be classified as case-based design aiding systems, they treat case representation differently. In ARCHIE-2, each case is a lesson-bearing story based on an architectural building case. ARCHIE-2's lessons focus on text annotations of design graphics where design issues or features such as a 'clerestory window' are highlighted and indexed. In SAM, each case is a building design episode with emphasis on structural and material design features represented texturally and graphically to the user.

Automation of reasoning functions usually results in higher levels of representational abstraction (e.g., in CADSYN, cases are machine coded in LISP and use a frame based language so case-data can be computationally adapted). In CADRE, graphically based data-vector structures represent spatial relationships between elements based on similar properties (i.e. location, sizes, function etc.). In some case-based design applications, the use of graphical data-vector structures enables machine based topological and textual adaptation). In addition, both CADSYN and CADRE store generalised design knowledge outside individual case-based design episodes. CADSYN for instance, stores much of its adaptation knowledge in the form of generalised adaptation rules (Maher et al., 1995) but CADRE uses model-based constraint interpretation instead (Faltings, 1997).

Other systems deal with automation versus human understanding issues by using multiple representational modules. For instance, FABEL contains different representations of its building project cases for all twelve of its associated retrieval systems. Some modules store images, others gestalts, and others tuples of values. Each case in FABEL is represented by a dynamically changing view depending on the task (Voss, 1997). SEED also uses task stages to differentiate representations for its three reasoning modules. In SEED-Pro (SP) a case contains structured collection of attribute-value pairs including the overall function and size of a building, budget etc. However, in SEED-Layout (SL), a case contains schematic layout data based on programmatic spatial components. Lastly, in SEED-Config (SC), a case contains three-dimensional layout data based on programmatic requirements. Disadvantages of multiple representational modules as used in FABEL and SEED include translating case representations between modules. In FABEL where case knowledge is specific to modules, this is particularly problematic. Additionally, FABEL's lack of a preset case format creates major case-based data acquisition problems (Voss, 1997).

FABEL's cases are based on large computer-aided drafting building projects, but are segmented into case components that have a type that determines their geometric and semantic attributes (subsystem, function, resolution and scale). FABEL also represents cases by assigning computational machine language graphical array structures to better deal with complex cases. The graphical array structures are then organised as concept hierarchies to preserve feature relationships.

These cases are thus a kind of 'nested graph-structure' as case features can be recurrently described by another set of interconnected but more abstract case nodes sitting higher up in the concept hierarchy. In this manner, abstract or generalisable features occurring in all instances are at the top of the hierarchy but concrete individualized instances are at the bottom. Nested graph-structures allow decomposition of a case into sub cases. Figure 3.18 illustrates a floor plan layout and its corresponding FABEL nested graph-structured representation. Nested overall curves are used to implicitly represent the hierarchical relations between case nodes (Macedo & Cardoso, 1998). Unfortunately, while machine readable, these types of images are still too abstract to be of much value to human users who can derive this sort of information visually more efficiently from viewing a digitally stored image such as a floor plan.

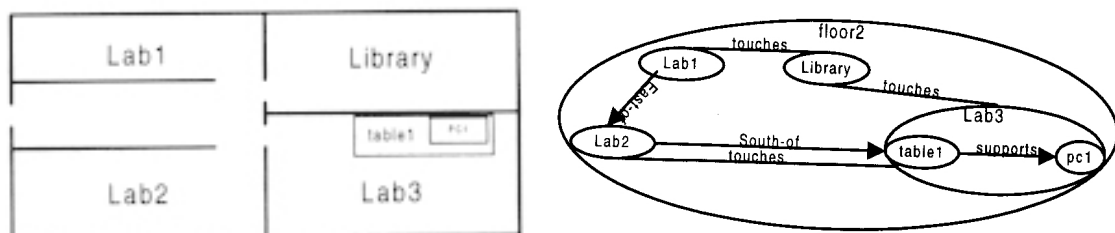


Figure 3.18: FABEL case using Nested Graph-Structured Representations (Macedo & Cardoso, 1998, p. 4 & 5)

3.5.2 Presentation of building design cases

Understanding the previous discussion of design case representations rests on familiarity with particular computational representational techniques. However, human-computer decision support and the foundation of usability lies in *presenting* case-based information in human, not machine, understandable form. Multimedia and multimode formats enhance interactivity by enabling the storage and retrieval of various media, such as graphics, text, video, and sound in a single case-based presentation (Maher et al., 1995, p. 163). This is important because helping practitioners understand redesign cases requires user-friendly representational media.

Graphic media in particular facilitate design communication because they convey spatial and geometric information to users more effectively than text. Furthermore, practitioners concerned with building redesign require both architectural and structural representation of cases to understand and evaluate potentially reusable solutions. Thus, provision of photographs, sketches and architectural drafting content facilitates multiple means of recalling and manipulating case-data. This is particularly important for browsing as an image can convey more information compactly than text alone. However, reuse of photographs and sketches remains limited as it rests on generation and storage formats.

Additionally, multimedia images and computer-aided drafting products cannot be indexed or searched without additional textual elaboration at the time of encoding as multimedia materials can currently only be machine handled for storage and retrieval purposes using either polyline (computer-aided drafting) or label descriptions (photos and sketches). Consequently, any design rationale implicit within the digital representation disappears if an image is viewed out of case context. Given the obvious advantages of multimedia, but in the context of contextual dependence limitations, presentation of case-based material will be most effective when multimedia and textual explanation encoding are integrated as neither suffices to meet both human and computational usability needs alone.

3.5.3 Case memory and case-part segmentation of building design cases

The way that individual cases are stored in the case library is referred to as case memory organisation. Segmentation is about organisation of case memory and case-parts so that they are marked off as though separable from the other parts. The organisation of design cases facilitates recall and is strongly associated with indexing, retrieval and case acquisition strategies. Segmenting a building design case into case-parts reduces difficulties associated with representing a complex problem as a single case (Maher & Pu, 1997). Segmentation schemas can be flat, feature based and/or hierarchical.

In monolithic or flat schemas, the cases present in case memory are represented as a list array or file for the purpose of search and retrieval. Search and retrieval proceed by examining each case in turn to find matches to input features (Kolodner, 1993). Flat schemas result in increased search time and greater inefficiency as the case library expands. A hierarchical structure allows retrieval and comparison of case-parts not just the whole case as a single entity. This is possible because hierarchical arrangements move from general attributes common to the whole case at the top or *root* level and then proceed down to specific case-parts that are unique at the lower *leaf* levels. Thus, leaves containing the desired case-part

knowledge can then be located and recalled. However, complete flat cases preserve more of the case context and users' prefer them for this reason (Voss, 1996).

Flat case storage systems can be made more efficient by segmentation of the case library into features (Kolodner, 1993). In reasoning using complex design cases, a hierarchical or compositional feature structure is commonly used to parse cases based on the representational and class structures selected. A hierarchy can be built by using a clustering system based on common features. Partitioning of cases can then be based on shared features where, for each partition created, a node is made which links back to earlier nodes. For instance, in SAM, the structural engineering building domain ontology differentiates Vertical/Lateral/Footing knowledge features and thus organises feature-based partitions (Maher, 1997). The case partitioning used in SAM is illustrated in Figure 3.19.

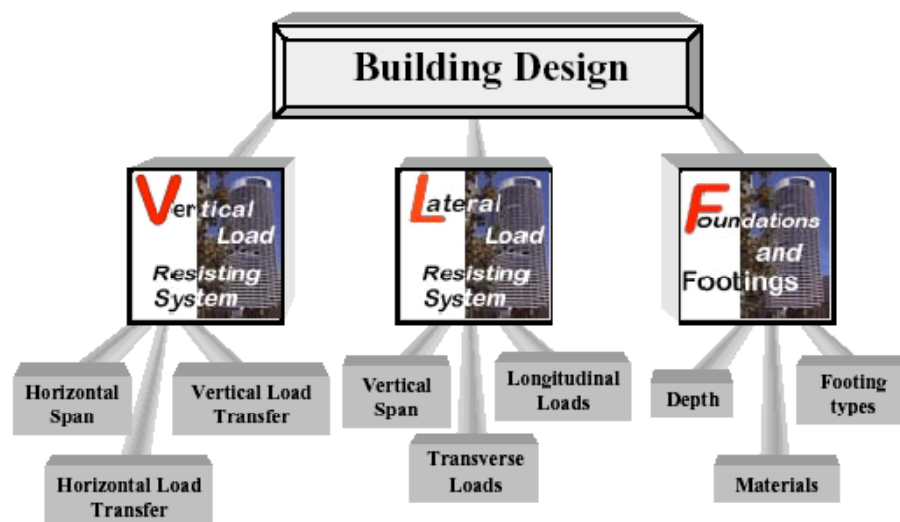


Figure 3.19: SAM's case-partitioning (Simoff & Maher, 1998b, p. 231)

In SAM feature-based partitioning occurs when *vertical*, *lateral* or *footing* knowledge is broken down into sub-models such as horizontal span, vertical span, footing types, etc.

Primarily flat simple feature-based case partitioning systems differ from hierarchical systems. In hierarchical systems, searching for a relevant case proceeds by starting at the top of the hierarchy and then moving downwards, stopping only when features at a lower level match the input parameters. For instance, CASECAD uses generalised structural design knowledge to segment case memory by grouping cases according to building class (Maher et al., 1995). Classes correspond to hierarchical groupings of certain building types (i.e. multi-storey buildings are partitioned into medium-rise versus high-rise). In this case, hierarchical inheritance of attributes from case classes assists both case segmentation and case memory organisation. A classification model that clusters building case features provides CASECAD

and CADSYN with an organisational structure for indexing cases. However, an inherent disadvantage of implementing a hierarchically structured feature-based matching process results when lower level branches that do not exactly match are overlooked despite potential relevance (Maher et al., 1995).

One means of overcoming the problem of feature-based matching is an organisational structure based on abstraction of concepts. In FABEL, cases are stored in a concept hierarchy with abstract cases on the top and concrete cases on the bottom. Boerner (1999) explains that when case memory is organised as a conceptual hierarchy, the activity of designing proceeds by first matching the concepts in order to locate a case that best matches the user's partial design input. In Figure 3.20, the five cases at the bottom are the most concrete and are grouped according to their conceptual similarity in terms of vertices and edges (i.e. direct pattern matching). Unfortunately, conceptual mapping, while allowing more abstract mapping, also increases the complexity of indexing and case acquisition.

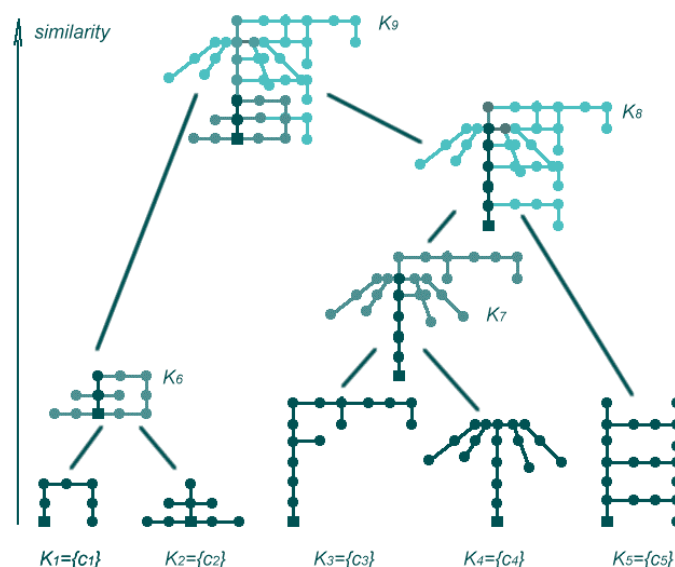


Figure 3.20: Case memory organisation as a concept hierarchy (Boerner, 1999, p. 5)

Whether feature-based or concept-based organisations are preferable depends on the domain and the purpose of the system. For instance, if the purpose of the system is to support creative design, then concept-based analogical segmentation will recall the most appropriate cases. If the purpose is to support a routine configuration design task, the emphasis will be on feature matching at concrete levels. Given that redesign reasoning occurs around concrete products, a feature-based segmentation will be a better choice for a redesign reasoner.

To date no one has considered segmentation formalisms specific to home modification cases. Hierarchical segmentation of home modification cases on the basis of building features alone presents difficulties because efficient redesign case retrieval requires matching critical parts

both of the original design and the new or additional requirements unanticipated in the original design. In this thesis, I develop a case segmentation schema that addresses these issues.

3.6 Limitations of case-based design models for redesign reasoning

In addition to the gaps in our understanding of case-based design, the issue of structuring and representing redesign cases for reuse has so far not been tackled. This chapter in particular, highlights pertinent issues in case representation, case presentation, case acquisition and case navigation including indexing, browsing and search strategies relevant to case-based redesign reasoning.

Redesign case-based representation breaks new ground. The only reference to case-based redesign in the literature to date relates to KRITIK (Goel, Bhatta, & Stroulia, 1992). KRITIK is sometimes described as a redesign tool because its mechanical design cases are transformed to meet new problem specifications. Although KRITIK can be said to assist redesign, its cases are *single* design episodes. In KRITIK, application of model-based adaptation knowledge, *not* redesign case knowledge, generates the new design solution. The adapted solution or redesigned mechanical device is then stored as a new case without linkages to the original source case. In other words, it closely follows the case-based design, problem, solution paradigm presented earlier, *not* the case-based redesign paradigm presented in chapter four of this thesis.

3.7 Reflexive³ Summary

In answering the question of how case-based reasoning theory could contribute to the redesign of spaces it was learnt that, while there are a number of case-based reasoning applications in design, many are able to store and reuse cases. However, none was capable of capturing or storing redesign learning or redesign cases without modification. This is because reasoning from redesign cases requires that any unique or additional attributes or processes within cases be explicitly defined and described.

Examination of the representational strategies previously applied to case-based design revealed that those most likely to assist a case-based redesign reasoning application were technologies like A-V feature pairs and object-oriented class structures. Nevertheless these generic formalisms need to be organised so they require an ontology capable of adequately semantically describing case features and their relations. The use of A-V feature pairs

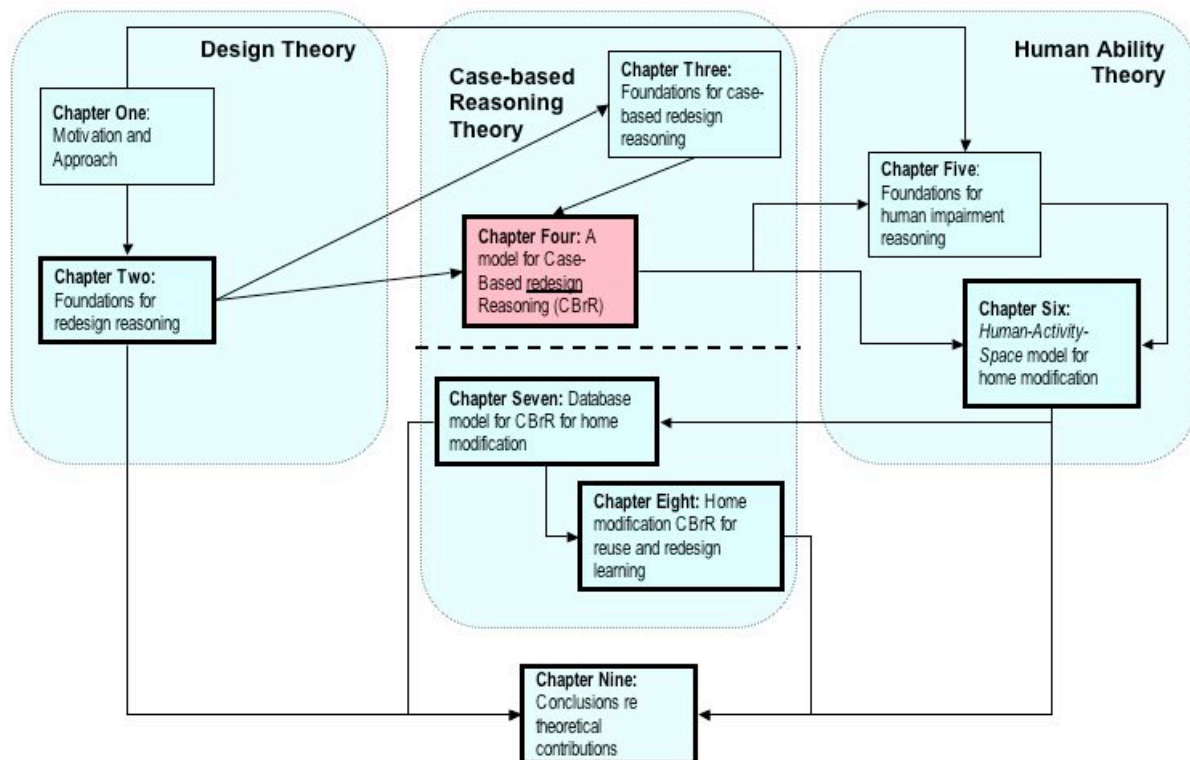
³ The word reflexive is used here deliberately as in action-based research the purpose is self-referential iteration with the objective of practical improvement (Mauthner & Doucet, 2003).

organised according to an ontological model allows the creation of compositional cases that can be organised hierarchically into a variety of abstraction levels. Implementing an ontological model alleviates some of the difficulties related to complexity of articulation while still providing flexibility in recall and a uniform structure for articulation of decomposition relations.

Additionally, it appears that graphical representation would be helpful but remains limited in terms of machine manipulation, as graphical reasoning is still in its infancy. Moreover, the use of multiple representational structures lacks appeal because of problems related to translation between computational encoding techniques of the various digital media inputs and results in issues associated with lack of any holistic case acquisition strategy. However, like many of the case-based design systems previously discussed, the strategy of utilising a machine-readable method for structuring related case-features hierarchically displays promise.

This chapter improved the understanding of possible case-based redesign reasoning techniques, and challenges the universality of some of the theoretical assumptions inherent in case-based design modelling so far undertaken. The research in theoretical subjects such as case representation and navigation strategies provides direction and foundations for the formalisation and representation undertaken in developing a model of case-based redesign reasoning.

4



A model for Case-Based redesign Reasoning (CbrR)

Chapter 4: A model for Case-Based redesign Reasoning (CBrR)

4.1 Introduction

This chapter presents a new model for case-based redesign reasoning. It does this by addressing the action-based objective of exploring: *how case-based redesign reasoning might be modeled?* Understanding case-based redesign provides a foundation for establishing and developing a case-based redesign system. Chapter two outlined the differences between design and redesign while chapter three provided the basis for understanding CBR as it has been applied to design. In this chapter, we build on these understandings to lay out the theoretical foundation that defines the modelling of key components required for a case-based redesign reasoner.

4.2 The structure of this chapter

This chapter develops a redesign process and product model. The chapter structure elucidates both the ontology underpinning component descriptions and the computational implications on reasoning processes. As outlined in chapter two of this thesis, aspects of redesign that differentiate it from design include the starting point, case contents, case browsing, case recall, case adaptation and case learning.

First, in order to distinguish the new CBrR model from previous CBdR applications, generic aspects of product representation and presentation are explored. This exploration details how redesign problems and solution descriptions differ. Second, following the exploration of what it means to describe something as a redesign problem or a redesign solution the relevant aspects that enable computational implementation are outlined. Presentation of computational formalisations necessary to enable the processes of browsing, recall, adaptation and case acquisition follow. These features provide the foundations of CBR task and method model knowledge blocks.

Third, the major advantages presented by the CBrR conceptual model are elaborated. Fourth, an overview of the implications for the domain of human ability is presented. The major issue for implementation is the extension of the CBrR model's ontological structure to explicitly include human activity and ability.

4.3 Foundations for Case-Based redesign Reasoning (CBrR) as a concept

Modelling redesign facilitates our understanding and reflection on redesign reasoning as a particular type of human problem solving and enables this to be exploited by a computational system. The model in this chapter, like all modelling activities involves abstracting reality. Thus appropriateness or validity depends on its ability to fulfil its purpose of communicating ideas in an internally consistent manner that is compatible with the reality to which it is intended to refer (Akin, 1982).

Knowledge engineering research as cited by Reynaud, Aussenac-Gilles, and Tort (1998) divides the modelling structure required for a knowledge-based system (KBS) into three interrelated areas as follows:

- ▶ a general task model, which describes the application goals and problems to be solved;
- ▶ a problem solving method, which represents the means and the control knowledge needed to achieve stated goals; and
- ▶ a domain model, which describes the specific ontological and theoretical knowledge of the domain.

The distinction into task, method and domain model components is important. The task model component represents an original contribution that refines understanding of the conceptual and pragmatic issues involved in redesign. This is similar to the task model framework as outlined by Steels (1990). The conceptual aspects of a task model component concern the kind of problem the task sets out to solve.

The redesign goal as outlined in chapter two, is to *integrate* new requirements with an existing design product description or artefact representation. Integration may mean modifying the original artefact features to better reflect the new requirements. The goal of *integration* is critical to redesign reasoning as to *integrate* means mixing or making into a whole disaggregate elements. In the process of reasoning about integration, CBrR allows us to store and search *integration* knowledge for later reuse.

Redesign has been defined as comprising the following set of features:

- ▶ the new redesign requirements;
- ▶ the set of existing object components; and
- ▶ the knowledge of how components are related.

Specification of input and output are central characteristics of any requirements modelling process. Therefore, although redesign as a task and its goal have already been articulated in chapter two, this is further elaborated and fully articulated in section 4.4.

CBR provides a generic methodological foundation for modelling process and control flow. The methods model component focuses on how tasks might be realised and how control flow will be executed. As a knowledge-level theoretical driven methodology, it does not restrict the way in which cases are implemented. Instead, it sets out *what* to represent (Langen, 2002), not *how* to represent it. However, a task system that reasons about redesign problems by reusing knowledge stored as cases is by definition concerned not just with the *what* of case contents but also with making explicit the *how* of problem solving. In addition, a case-based foundation parallels human experience and exploits redesign cases as the basis for recalling, adapting and learning about redesign problems and solutions.

4.4 Case-based reasoning as a redesign product model

Case-based redesign reasoning (CBrR), because it is founded on CBR theory, works on the assumption that reuse of the redesign experience can be aided by recalling similar prior redesign cases. This difference is far from trivial. While CBR provides the basis of the problem solving method, the CBrR model developed enables recall surrounding redesign reasoning by defining the problem in terms of new requirements in relation to an existing design description. In chapter three of this thesis, the notion that case-based problem solving principles exploit similarity by matching between existing problem description and solution spaces was explored. CBrR has the same foundation but the problem description is extended to an existing design in addition to the set of new requirements. Figure 4.1 illustrates this dual input. Dual input distinguishes redesign from design and bounds the redesign problem space.

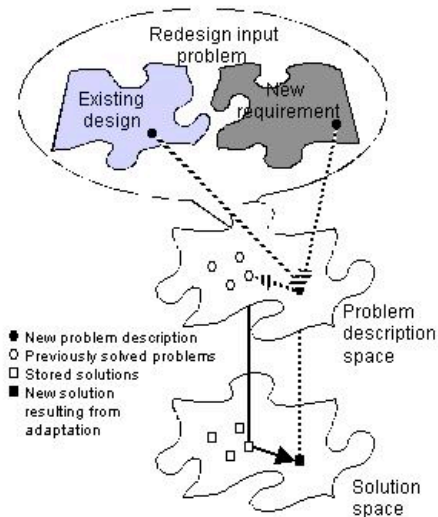


Figure 4.1: Basic CBR problem solving principles (adapted from Leake, 1996, p. 8)

The understanding derived from knowing the relationship between design and redesign, as articulated in chapter two of this thesis, demonstrates how design problems evolve out of attempting to better understand key constructs, view them from multiple perspectives, and then describe them again in more familiar terms. In design, this is how conceptual design moves from concept to product. Design problem descriptions evolve out of the process of design exploration and elaboration.

Breaking design problems down into their most concrete or lowest level of detail facilitates this exploration and elaboration processes. It is for this reason that there have been numerous international efforts to attempt to describe built object terminology with greater precision (Wright, 1998). Furthermore, Booch (1994) suggests that the ability to decompose complex problems into smaller and smaller parts enables understanding of part and part relationships. It is the ability to explore a design problem at a given level of detail that facilitates human understanding and enables the derivation of clearly defined relationships and constraints. This understanding of design echoes previous ones like that shown in Figure 3.7, which illustrated the importance of concept refinement as an intrinsic part of any design process.

The redesign process, on the other hand, commences with low levels of specific concrete knowledge, moving on to the more abstract concepts so as to understand compositional organisation prior to redesign refinement which leads back to a concrete redesign solution. A redesign problem results from evaluation of the impact of integrating new requirements with an existing design and occurs because new requirements were not anticipated as a part of the original design process. Figure 4.2 illustrates the idea that redesign commences and ends concretely while reinforcing the notion that as in design there is a potential for compositional organisation knowledge to be used to make the problem more tractable.

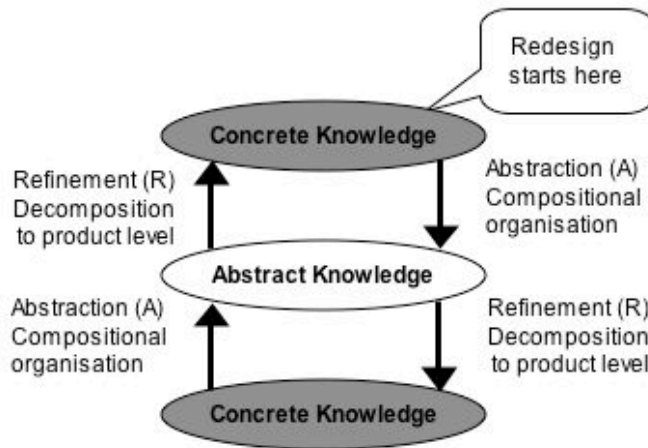


Figure 4.2: Problem solving in redesign starts with concrete knowledge

4.4.1 What are redesign problems and how might they be represented?

Redesign problem specification provides the basis for the reasoning processes related to recall and reuse. As has been discussed, a redesign problem is fundamentally different to a design problem in that input requires a design solution plus the new requirement. Nevertheless, as in the generic CBR process model, reasoning commences by taking the input problem and generating a problem description. This insight is applied to both a design problem scenario and a redesign problem scenario to provide greater clarity. Table 4.1 illustrates this very simplistic comparison of problem product representations between design and redesign to clarify how problem descriptions differ in a redesign model.

Table 4.1: Problem descriptions in design and redesign cases

Domain	Problem description
Design	<i>problem = set of design concept requirement descriptions (i.e. design home in Spanish style)</i>
Redesign	<i>problem = set of redesign requirements (i.e. wheelchair access) AND existing design product descriptions (i.e. full brick home in Spanish style with door widths of 600 mm and several changes of level internally).</i>

As can be seen, the primary difference in a redesign problem description lies in the fact that reasoning and reusing redesign cases required additional knowledge be explicitly stored. A redesign case must capture the new redesign requirements in addition to capturing any existing design descriptions. In other words, reuse of redesign cases requires that the new redesign goal (e.g. providing additional security), which was unanticipated by our designer during the original conceptual design phase, must also be explicitly encoded otherwise it cannot be retrieved and redesign learning is lost.

A straight design scenario occurs when a designer undertakes to conceptualise a new product such as a building. For instance, when Jorn Utzon was commissioned to design the Sydney

Opera house, part of the design brief involved specification of some of the primary function (e.g. provision of performances spaces). However, as is typical, it did not specify design detail particulars e.g. fitting and fitout particulars, like the exact number or type of seating, stage sizes and viewing distances. Instead, these evolved as conceptual design decisions were made hierarchically. In this case decisions were made about form and only later were decisions made about how design particulars such as drainage services could be solved (Drew, Utzon & Browell, 1995).

In a design session, the designer commences with conceptual or abstract goals as relevant to a particular product. On the other hand, in architectural conservation work, which is primarily about restoration or redesign, reasoning starts with the product ‘as found’ or measured (Patterson, 1982). As found descriptions differ markedly from design descriptions because they convey detail about the product as it exists, i.e. poor maintenance or subsidence must be captured as they impact redesign decision making.

Thus, a redesign session commences by recall of existing products based on actual values either to better understand the components under consideration or to find a particular case that is similar enough to the new problem to be reused. If our redesigner can locate a case that is sufficiently close to the new problem description with sufficient design description compatibility reuse becomes an option. However the complexity and differences imposed by combining both redesign requirements and detailed design object descriptions embodying *as found* design product detail means that in nearly all cases change or adaptation is necessary. Obviously the closer the similarity the less adaptation will be required. In all CBdR applications, because redesign requirements are not explicitly stored, the rationale for the changes and the knowledge of what was changed is lost when a solution is reused as the basis for a new design case.

Having clarified generic difference in problem description definitions between design and redesign, we can now illustrate the differences more concretely in the building domain using more mathematical and logical formalisms (i.e. set notation). The concept of sets and set theory is of fundamental importance to the computational application especially in the area of data base structures. In set notation, a *set* is defined as a list or string of well-determined objects grouped into a single whole. These objects are then called the *elements* of the set. Table 4.2, below provides some set notation examples.

Table 4.2: Building design problem comparison

Building Domain	Problem description	Example using set notation
Office Design	<i>Office Specification</i>	{site = 1000 m ² , budget = \$20 million,...}
Office Redesign	Redesign Requirement AND Office Description	{security = increased,...} {hi-rise. 14-levels,1-elevator, ...}

As can be seen in Table 4.2, one of the obvious differences in set contents between design and redesign problem descriptions relates to specification of a design problem using vocabulary at a high level of abstraction (Vollrath, 1998). For instance, design problem descriptions are typically ill-specified or vague in nature and thus may not specify details as to all the desired values such as the number of levels or elevators. On the other hand, redesign description vocabulary because it has to capture elements ‘as found’ sit at a much lower level of abstraction. This results because the design problem description explains abstract requirements only but a redesign problem description states both redesign requirements and the design product components ‘as found’.

4.4.2 What does it mean to say that something is a solution to a problem?

The CBrR scenario just outlined requires the designer to recall a case using both their existing design solution and the new redesign requirement. For example, going back to a design case-base and trying to recall a building case with greater security may not be very helpful because, unless it is pretty close to the original design, the designer will have a lot of transformations to carry out. But of greater significance in understanding what it means to call something a solution to a problem, our standard design case using traditional case description will also be silent about what changes or transformations will make an old case fit the new redesign problem scenario.

A traditional case-based building design solution description contains just the design product description, which may or may not include a security component. In the redesign model developed in this thesis, a solution is defined as the knowledge of all the changes the designer had to make to accommodate the new requirements. In other words, it represents the *transformation knowledge* of redesign. So the designer who was asked to modify their original design to include greater security would store as the redesign solution all the changes they had to make in order to accommodate the client’s new request. Storing the redesign solution could be of great benefit to our designer as next time they were required to modify security they would now be able reuse this case knowledge to recall components affected and the amount of modification required.

Having clarified generic difference in solution description definitions between design and redesign, we can now illustrate the differences more concretely in the building domain as before using set notation. Table 4.3 illustrates this very simplistic comparison of solution representations between design and redesign to clarify how solution descriptions differ in a redesign model.

Table 4.3: Comparison of design and redesign solutions

Domain	Solution description
Design	<i>solution = set of design product descriptions</i>
Redesign	<i>solution = set of design transformations AND set of redesign product descriptions</i>

Having clarified generic difference in solution description definitions between design and redesign, we can now illustrate the differences more concretely in the building domain using set notation as follows in Table 4.4.

Table 4.4: Building design solution comparison

Building Domain	Solution description	Example using set notation
Office Design	<i>solution = set of design product descriptions</i>	{hi-rise, 14-levels, 1-elevator, ...} OfficeDescription
Office Redesign	<i>solution = set of redesign outcomes AND set of redesign product descriptions</i>	{security = increased, ...} RedesignOutcome {add-motiondetection, add-grillslevel1, relocate-safe ...} OfficeRedesignDescription

Now we have defined what a product and a solution look like in a redesign case, we can now proceed to further formalisation of a redesign case model. A symbolic formalisation of design cases as a simple tuple has already been outlined symbolically by Maher et al. (1995, p. 112) as follows:

$$C^d = \{C^p, C^s\}$$

Where C^p is the design problem description, and

C^s is the design solution description

Following this format, a redesign case formalism can now be defined symbolically as the following:

$$C^r = \{C^{rp}, C^d, C^{rd}, C^{rs}\}$$

Where C^{rp} is the new redesign problem description,

C^d is the existing design description,

C^{rd} is the redesign description; and

C^{rs} are the actions used to transform the original design to the new redesign description.

We can now apply this to a straight and explicit redesign scenario for further illustration and clarification. Our redesign scenario might commence with someone getting fed up with putting too much salt in their food and thinking that the solution would be to redesign a teaspoon so that it had a smaller sized bowl more suitable for scooping salt. The redesign task then becomes one of integrating the new requirement of smaller bowl size into the existing teaspoon design. Using the redesign formalism given above we can now describe our redesign of a teaspoon case as follows:

4.4.2.1 Teaspoon case component representation

$C^{rp} = \{\{\text{decrease-bowl}, \dots\} \text{RedesignRequirement}\}$

$C^d = \{\{\text{medium_bowl}, \text{medium_handle}, \dots\} \text{TeaspoonDescription}\}$

$C^{rd} = \{\{\text{tiny-bowl}, \text{small-handle} \dots\} \text{SaltSpoonDescription}\}$

$C^{rs} = \{\{\text{remove-bowl}, \text{add-tiny_bowl}, \dots\} \text{Teaspoon-SaltSpoon-Transformation}\}$

4.4.2.2 Teaspoon case description

$C^r = \{\{\{\text{decrease-bowl}, \dots\} \text{RedesignRequirement} \{\text{medium_bowl}, \text{medium_handle}, \dots\} \text{TeaspoonDescription} \{\text{tiny_bowl}, \text{small_handle} \dots\} \text{SaltSpoonDescription} \{\text{remove-bowl}, \text{add-tiny_bowl}, \dots\} \text{TeaspoonRedesign}\}$

4.5 Redesign process as a case-based reasoning model

The differences between CBdR and CBrR are made clearer if we present them graphically. As Figure 4.3 illustrates, a critical difference is what is stored and how it is organised.

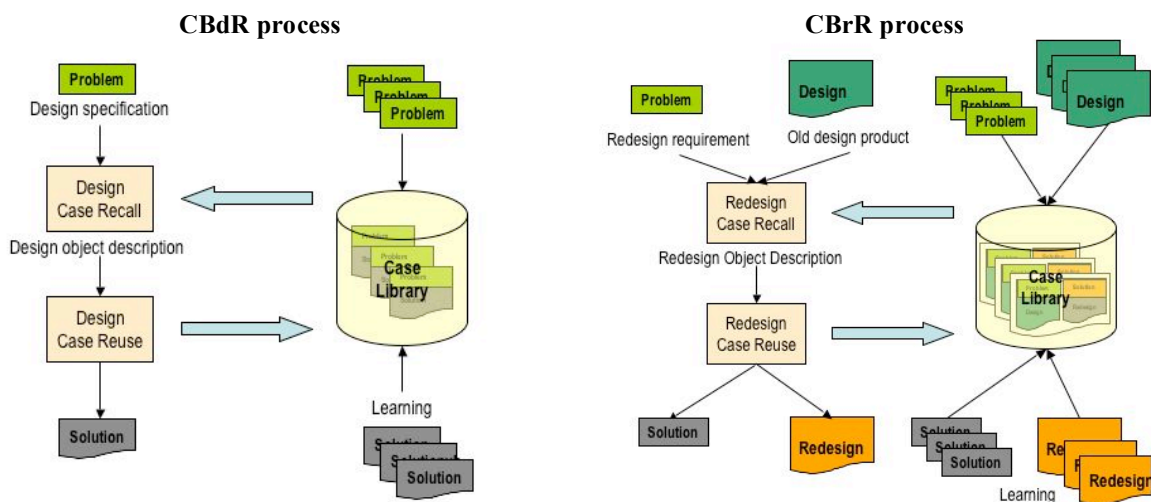


Figure 4.3: Illustration of differences between CBdR and CBrR processes

In a typical case-based design session, a sample input query or design problem recall data by pattern matching against existing case indices. On the basis of the match, cases are ranked and retrieved for evaluation. For instance, a designer might be commissioned to design a church with certain features such as a bell tower and a nave to cover a certain amount of site area. The CBR system uses aspects of the input problem such as building type, area, nave shape or existence of a bell tower to check case indices, selecting and ranking the most promising similar design solutions from its case-library for review and evaluation. The designer then either reuses the old design if an exact match can be found (i.e. routine design), or attempts to adapt the old design solution to the new situation (i.e. creative design).

Adaptation might be required because the available site area or orientation in the new problem may not exactly match the case that was recalled. Adapting or reducing the proportion of the nave in order to fit the input query's smaller land area might be feasible and, once accomplished, the now scaled down nave design solution can be stored together with its input query as a new design case.

The process of adaptation produces *transformation knowledge*. Many case-based design systems fail to store *transformation knowledge*, and design cases are simply collections of problems and solutions. Thus indexing, retrieval and selection are based on problem and solution content not transformation knowledge. As previously discussed, *redesign* means to revise, modify, adjust or alter appearance, function or content, so a CBrR also differs from a CBdR in that case storage, indexing, retrieval and selection need to capture transformation knowledge. Capturing transformation knowledge means encoding the transition steps; in other words, encoding knowledge about what was changed.

The traditional case-based design scenario does not work well for redesign problems, not just because of failure to store transformation knowledge, it also fails because redesign problems are constrained not only by abstract concepts such as building type or class but by product features. Redesign problem solving relies on knowledge of the original design product, additional or unanticipated requirements and knowledge regarding the sort of transformations undertaken to solve similar redesign problems in the past.

In chapter two, redesign was discussed as a set of reasoning tasks and was compared to the reasoning tasks of design as conceptualised by Reich (1991). Reusing the redesign task structure makes possible more direct mapping of CBR tasks. Figure 4.4, illustrates this mapping between redesign tasks and CBrR tasks. In Figure 4.4, the 'x' just signifies a particular specification within a wider space of possibilities.

Case-based recall or user directed browsing functions enable relevant prior redesign cases to be returned for reuse. The reasoning process then commences with evaluation. The function of evaluation concerns the act of ascertaining or fixing the worth of something. The evaluation task may be assisted by reusing the *redesign solution* containing *previous adaptation* knowledge in combination with *case-based classification* knowledge to identify those features of a redesign case that are valued and so retained for reuse and/or those that will require adaptation.

Once features that require adaptation have been identified, new features can be added, old features can be removed, or values can be substituted and/or parameters adjusted to either repair or reposition them. Adaptation requires synthesis knowledge (Maher et al., 1995) and thus may be assisted by *case-based configuration* knowledge (Wilke et al., 1998).

Formulation means creating a new set of explicit redesign goals so that the new case can then be acquired for future reuse.

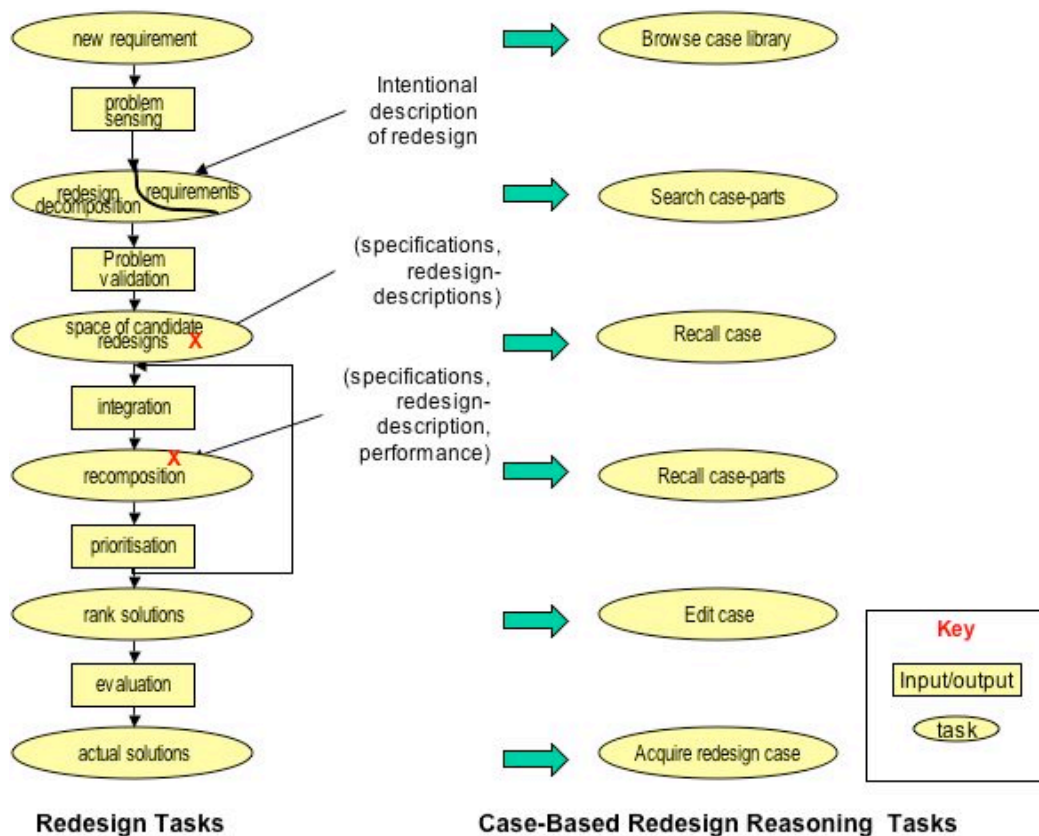


Figure 4.4: Mapping of generic redesign tasks to specific CBR tasks

The differences between case-based design and redesign mean that case-based redesign presents opportunities for resolving some documented case-based design issues associated with capturing object decomposition and adaptation knowledge. However, it also presents new case-based challenges in terms of revision of algorithms required for indexing, retrieval

and selection of the knowledge represented in a redesign case. Inclusion of adaptation knowledge and explicit product representation results in redesign cases containing significantly more detail.

4.5.1 Browsing in a CBrR system

In chapter three, the review of existing CBdR browsing applications revealed that structuring of both the case-base and cases in a manner transparent to users was beneficial. Web-based systems, for instance, commonly employ site navigation maps. Site navigation maps and internal case structuring at component levels is unaffected by differences in redesign case representation. For example, the Function-Behaviour-Structure design prototype can be used to structure all three-redesign input and output components. Graphical summarisation of cases and case parts are other enhancements commonly applied to design that would also assist directed redesign case browsing. However, these techniques assume a standard problem-solution case structure and are application domain specific; for example, the hierarchical artefact class model specific to structural engineering design that was used by SAM (Maher, 1997).

A problem-solution case structure in the building design domain typically reflects some modelling of building types. Thus, a logical structuring for improved browsing might reflect relevant building types. Representation of types depends on the domain but might include houses, shops, libraries, office buildings and entertainment venues. Presumably, different building types can then be broken down further for greater specificity into different component or class structures.

However, structuring browsing based solely on a particular building design type or even new requirement type may not be particularly helpful in a CBrR because the case representation structure is different. The whole idea behind structuring of browsing requires a method of grouping cases in a logically coherent and transparent manner to facilitate case recall. However, the usefulness of groupings depends on the goal or intent of both the user and the system.

4.5.2 What does it mean to look for a solution?

Structuring of a case-base requires reflection on solutions. In a CBrR system, browsing cases requires access to and transparency of *integration* knowledge. Understanding the integration of new requirements with an existing design is what makes a case more or less suitable for reuse. In providing a structure for assisted browsing of a case library, knowledge of the original design, new requirements, and redesign solutions are all equally important. Therefore, in a system where the goal is redesign, the most helpful structuring techniques for

browsing within a CBrR needs to reflect redesign case contents that are not just problem-solution descriptions.

Browsing based on only one aspect of case contents is unlikely to be overly helpful in selection of cases for reuse, particularly in a large case library. Figure 4.5 illustrates how the new redesign model can be used to structure browsing for viewers by offering multiple views into the case library depending on the relative importance of the three features of a redesign case from the users' perspective.

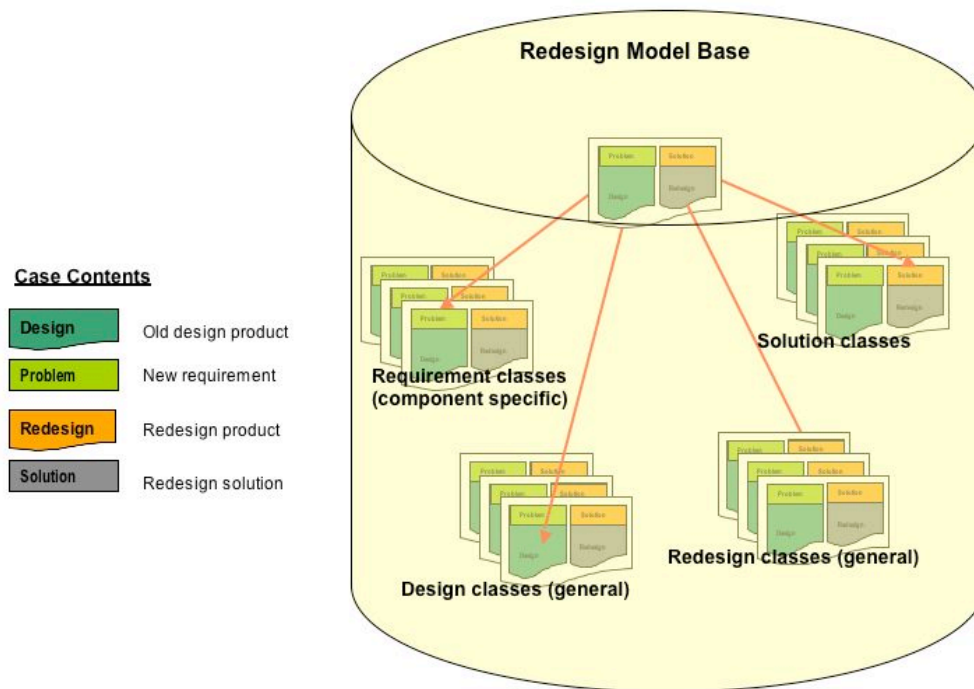


Figure 4.5: A means of structuring browsing based on the redesign model

We can make the benefits of this more obvious by returning to both the spoon and building case examples. If we take the more simplistic spoon domain first, some examples illustrating the three classes are provided in Table 4.5.

Table 4.5: Example of browsing structure for spoon domain

Object Description Classes	Redesign Requirement Classes	Redesign Solution Classes
<ul style="list-style-type: none"> ▶ Ladle ▶ Soup ▶ Tea ▶ Salt etc. 	<ul style="list-style-type: none"> ▶ Bowl size ▶ Bowl depth ▶ Handle shape ▶ Handle material etc. 	<ul style="list-style-type: none"> ▶ Simple ▶ Moderate ▶ Extensive ▶ Infeasible etc.

The idea of classes allows the user to browse a case-base by using the type categories (i.e. object, requirement and solution types). Structuring browsing in the manner proposed does not require 'hard' partitioning of cases. Browsing based on classes depends instead on user preference. The category spoon types permits the user to browse other similar product

descriptions to obtain an overview of differences based on components and component relationship descriptions. The new requirements permits browsing by examination of primary redesign features, while the solution classes facilitate learning about the extent and type of redesign that might be required.

Table 4.6 further exemplifies the application of browsing classes to the building domain area. The spoon domain example was provided first, because the narrowness and simplicity of the domain makes it relatively easy to understand. However, inclusion of the more complex building domain enables cross-domain comparison and builds on the domain understandings already provided.

Table 4.6: Example of browsing structure for building domain

Object Description Classes ⁴	Redesign Requirement Classes	Redesign Solution Classes
<ul style="list-style-type: none"> ▶ Class 1a - House ▶ Class 1b - Small boarding house ▶ Class 2 - Flats, Villa Units ▶ Class 3 -Hostel, backpackers, Hotel/Motel ▶ Class 4 – Caretakers residence ▶ Class 5 – Office ▶ Class 6 – Shop, Restaurant ▶ Class 7 – Carpark, Warehouse ▶ Class 8 – Laboratory, Factory ▶ Class 9a – Hospital, Nursing Home ▶ Class 9b – School ▶ Class 10 – Non-habitable building 	<ul style="list-style-type: none"> ▶ Security ▶ Temperature ▶ Electrical ▶ Acoustic ▶ Circulation ▶ Lighting ▶ Plumbing ▶ Flooring ▶ Drainage ▶ Finishing ▶ Furnishing ▶ Space 	<ul style="list-style-type: none"> ▶ Add ▶ Remove ▶ Substitute ▶ Relocate

Comparison of the spoon and building examples illustrates that a browsing structure based on redesign case class partitioning can be generalised across domains. However, differences in the specific interpretation of class structure between domain areas also illustrates that class specifics will vary depending on the application domain, degree of complexity and degree of established domain understanding.

4.5.3 Recall in a CBrR system

Case-based recall, unlike the less structured user-directed browsing strategy just outlined, requires implementation of a computational means for searching or systematically exploring a case-base. Search requires navigation of the case-base based on index matching and similarity calculation. Once suitable cases are retrieved they then need to be ranked and selected. The degree of automation and computational method varies depending on the goal of the system.

⁴ Building Code of Australia class categories

An index represents an abstract summary or label for a case and thus must capture the main characteristics or features relevant to retrieving that case. In CBrR, the indexing scheme used needs to capture critical artefact features at new requirement and existing design description levels, particularly where the existing design description components have been modified as a part of the CBrR process. This is because the original design description components that will be most relevant to the new problem are most likely to be those features that were adapted to create the integrated redesign solution. This corresponds with the indexing vocabulary criteria of prediction and specificity outlined by Kolodner (1993) and expanded in relation to design by Maher et al. (1995). Meaning that just indexing all the existing design descriptions from a redesign case and using these to match directly with those present as components in the new problem input, might not adequately discriminate between cases.

In terms of indexing and retrieval, the best cases are the ones that most accurately predict solutions and provide the most knowledge about reusable features. Indexing and matching on component features present in the existing design description, but which were not present in the redesign solution, could well retrieve cases that are irrelevant and would require a more exhaustive search of case memory. For example, cases in the building redesign domain contain building redesign formulations and thus require indexing related to the component features involved in redesign formulations. For instance, knowing that a grabrail is required in a bathroom will not retrieve useful solutions unless the input query also contains information about the original bathroom, such as proximity to an appropriate structural support like a wall strut. Both the input query and salient data about the original design are required to recall helpful redesign cases.

The indexing process must therefore take into account the redesign case formalisation. The process for indexing a case associates each case with a list of indexing vocabulary features and adds new features only if they are not already present in the existing list. Case recall can then use the variable *indexing-list* to match features to case labels. This process is computationally illustrated using pseudo code⁵ after (Maher et al. 1995) as follows:

Index case

begin

 add the case label into case index;

 for each feature(i) of the redesign requirements (C^r) and the set of object description attributes (C^d) where they correspond with the redesign solution description attributes (C^{TS}) in the case

 get the list of case labels associated with this feature(i)

 from *case indexing list*;

⁵ The word *feature* is used in the pseudo code rather than *attribute* because a *feature* can have one or more *attributes* whilst an attribute is part of an A-V pairing thus is at the leaf level or lowest point of any feature description hierarchy.

```

if the list of case labels is empty
    then add feature(i) into case indexing list;
        create a list containing the case label;
        associate this new list with feature(i);
    else    add the case label into the list of case labels;
end

```

end

A more detailed look at query input reveals its impact on case-based recall. The redesign task in our example is the integration of a new alarm system into a medium rise office building. Table 4.7 illustrates an input query where elements are simple A-V pairs for clarity. In the example it is clear that the more specific the input the more closely the case recalled will match the reuse scenario.

Table 4.7: An example of how the problem description affects recall

Query Input		
<ul style="list-style-type: none"> ▶ Redesign requirement = {fire-protection=true} ▶ Subset of object descriptions = {Material_Insitu-RC, Total-level_17, Overall-shape_Rectangular} 		
Case 1	Case 2	Case 3
<ul style="list-style-type: none"> ▶ Case: 370-Pitt-St ▶ Instance-of: Med_rise_building ▶ Overall-shape: Rectangular ▶ Material: Insitu-RC ▶ Total levels: 17 ▶ Fire-protection: false 	<ul style="list-style-type: none"> ▶ Case: 130-Elizabeth St ▶ Instance-of: Med_offset_building ▶ Overall-shape: Rectangular ▶ Material: Insitu-RC ▶ Total levels: 17 ▶ Fire-protection: true 	<ul style="list-style-type: none"> ▶ Case: Parramatta-Hotel ▶ Instance-of: Med_offset_building ▶ Overall-shape: Rectangular ▶ Material: Insitu-RC ▶ Total levels: 17 ▶ Fire-protection: true
Case recall		
<ul style="list-style-type: none"> ▶ On basis of ‘Redesign requirements’ alone = Case 1 & 2 ▶ On basis of ‘Subset of objects description’ alone = Case 1, 2 & 3 ▶ On basis of integration of ‘Redesign requirements’ & ‘Subset of object description’ = Case 3 		

4.5.4 What does it mean to say that something is similar?

Case-based recall of a prior redesign case implies that correspondences between the new redesign requirements and the object description subset used as input can be computed against cases already in the case-base in some manner. As previously discussed in chapter three, the most common form of similarity measurement in case-based design reasoning (CBdR) systems is nearest neighbour matching using relative importance of features. This tends to produce better results by allowing the user to articulate priorities in relation to query context (Kolodner, 1993; Maher et al., 1995).

The most convenient manner of checking similarity is to calculate the distance based on pairwise comparison of attributes (Bock & Diday, 2000). For instance, if A is an attribute of case 1 and B is an attribute of case 2 we can now formalise this as follows:

$$C^{\text{base}} = \{A, B\} = 0 \text{ if } A \neq B$$

$$C^{\text{base}} = \{A, B\} = 1 \text{ if } A = B$$

where C^{base} stands for our case-base or case-library.

The comparison of similarity of attributes between cases can be clarified by denoting the four similarity matching results possible. Consequently similarity proceeds, with the total number of matches being calculated on the basis of matching between all elements of the set of attributes selected by the user as important, and contained in redesign descriptions. For instance, for recall to occur one or more elements from the redesign sets C^{rp} , C^{d} , C^{rd} , and C^{rs} must be compared and the results of matches or non matches must then be summed. The most similar case will therefore be the case with the highest matching score. If we take an attribute from the set of new requirements and apply our similarity matching metric for each element in the set, the four possible result options are as illustrated in Table 4.8.

Table 4.8: Attribute comparison matching options based on a similarity

Options	Similarity criteria
a	Number of matching components where $C^{\text{n}}_{\text{case1}} = C^{\text{n}}_{\text{case2}} = 1$
b	Number of non-matching components with $C^{\text{n}}_{\text{case1}} = 1$ and $C^{\text{n}}_{\text{case2}} = 0$ (no value provided)
c	Number of non-matching components with $C^{\text{n}}_{\text{case1}} = 0$ and $C^{\text{n}}_{\text{case2}} = 1$ (no value provided)
d	Number of matching components where $C^{\text{n}}_{\text{case1}} = C^{\text{n}}_{\text{case2}} = 0$

Nevertheless, the way a case is indexed determines what will be considered for retrieval. In many CBR systems, case labels are based on indexing features that correspond with case contents described as set-valued attributes. For example, the way buildings are grouped may involve set-valued attributes because a building may have several different kinds of properties or incorporate multiple functional or activity profiles. For this reason, many CBdR systems also use local similarity metrics for dealing with set-valued attributes. To illustrate what this means for retrieval of cases from a case-base, suppose we defined A_i as a set-valued attribute of a case (i.e. activities enabled) and a_i as the set of potential values associated with it (i.e. bathing, toileting, grooming,...) as in the following algorithm:

$$\text{Sim}(A_i, B_i) = |a_i \cap b_i| / |a_i|$$

For further clarification, consider rooms D, E and F, with the following values for their functional purpose feature:

D: {bathing}

E: {bathing, toileting, grooming}

F: {grooming}

This similarity metric looks at the size of the feature set intersection relative to the size of the set in the query case. So, the degree of similarity between D and E is maximal, because E overlaps with everything found in D. However, the similarity between E and D is less because D only contains a third of what is found in E. This metric assumes that a user looking for a room that afforded bathing activities would be satisfied by a room that accommodated both bathing and grooming, but one looking for a room that combined bathing and toileting activities would not necessarily be happy with a room that focused on one or the other.

Given a new redesign problem, the case labels associated with any corresponding features are recalled. For each redesign requirement feature and object feature provided, the cases recalled are those that have the highest number of corresponding features. However, CBrR requires matching of both the new requirements plus features of the original case around which modification will occur. This is both a restriction and a refinement of the similarity evaluation function given above. It is a restriction because each case in the case-base requires matching not just on the input query but also on features of the design case. This works like a Boolean *AND* operator to reduce the set of potential cases returned to those that demonstrate a union of features. It is a refinement because it improves the nearest neighbour similarity function for redesign reasoning by altering its matching function.

The similarity metric will return a list of cases. These cases are then numerically ranked according to their match of features given a user assigned importance value. When the case library has more than one case, the retrieve process has to create a temporary variable called *retrieved-cases* in order to list the cases that match during the recall process. The process of case retrieval can be computationally illustrated using pseudo code (after Maher et al., 1995) as follows:

Retrieve case

begin

 retrieve the case label from case index;

 for each {feature(i); value(i)} set used in input;

 find the list of case labels associated with the feature(i)

```

        from case indexing list;
    if the list of case labels is not empty
        for each case(i) in the list of case labels
            assign a similarity value to the case(i)
            if similarity value of {feature(i); value(i)} comparisons = 1
                then add the case(i) into retrieved-cases
            else if similarity value of {feature(i); value(i)} comparisons = 0
                repeat until all {feature(i); value(i)} comparisons complete
    end

```

Redesign retrieval depends on the matching of features derived from the new requirements and the original design description with an indexing list containing features corresponding to features of redesign solutions. However, recall of cases also requires a case selection process. Selection of cases can be achieved either computationally by isolating and returning the case with the highest similarity value or by permitting the user to select from the full list of the retrieved cases identified during the retrieve process.

Retrieving redesign cases based only on a narrow feature set, such as the redesign requirements alone, will not guarantee the recall of suitable cases. Using the new redesign model, selection and ranking will be improved the more closely they correspond with the more comprehensive redesign case description. For instance, the best case to select will be one that contains features from both the redesign requirements and the ‘as found’ object description. This strategy allows for both strong and weak retrieval and selection (Kohler, 1994). Strong selection being where the retrieve and ranking processes only list or rank cases which contains features of both C^p and C^d . However, weak selection occurs when the list of retrieved-cases includes cases that contain only features corresponding to a part of the input problem i.e. C^p or C^d .

The process of computational ranking involves matching the redesign input against the *retrieved cases* lists previously generated. The matches for retrieved cases are stored in temporary array variable *matches*. This ranking process is illustrated using pseudo code (after Maher et al., 1995) as follows:

```

Rank case
begin
    initialise matches(i) to 0 for all cases(i) ;
    for each case(i) in the list of retrieved-cases
        if case(i) contains {feature(i); value(i)} sets that correspond to (new case)
            then add one to the value of matches(i) of case(i);
            if matches(i) is not empty
                then find the largest matches(k) in the matches;
                get case label in retrieved cases corresponding to matches(k);
            else for each case(i) in the list of retrieved-cases

```

```
        if case(i) contains feature(i) that correspond to ( $C^b$ ) or feature(i)
           that corresponds to ( $C^d$ ) or {feature(i); value(i)} that corresponds to
           ( $C^{ts}$ )
           then add one to the value of matches(i) of case(i);
        find the largest matches(k) in the matches;
        get case label in retrieved cases corresponding to matches(k);
end
```

Evaluation for fit thus becomes possible once the best matching redesign case has been recalled. In a similar way to the spoon case example, our spoon might require some adaptation, such as increasing the handle width to better suit the users' grip pattern or reach range.

4.6 Reuse learning in a CBrR system

In chapter three, case-based adaptation was touched on but not explored in depth as it is a major research area by itself and is not part of the original contribution of the redesign model presented in this thesis. However, while the new model of redesign outlined within this thesis says nothing about how the transformation process actually occurs (i.e. computationally or manually), it is unique in that the redesign solution component stores transformation knowledge for recall and reuse. In other words, no matter whether the transformation process is automated or left entirely to the user, as many case-based aiding systems do, retrieving a redesign case means that previous transformation knowledge can be reapplied.

Unfortunately, computational adaptation models typically require a strong domain theory capable of isolating and generalising sets of transformation actions. So while it might be quite simple to have a formula which takes a value such as height and alters it in relation to another feature in the new case, it requires knowledge of how synthesis can occur and this requires knowledge of synthesis which is very difficult to abstract and encode in a meaningful way computationally. Furthermore, the need to keep track of components and their compositional relations increases adaptation complexity in redesign cases. This becomes evident when we consider that the activity of redesign usually means that the redesign object descriptions within an existing case may require modification in more than one area depending on context. To illustrate this further, we return to our earlier redesign problem example where a redesigner was asked to incorporate greater security into an existing building. If our redesigner were using a CBrR system to recall a previous redesign solution, our designer may also be reminded that motion detection and grilles are relevant. However, the actual number and position of these security features will depend on careful analysis of the new context. For instance, installation of grilles on level two might not be required or recalled unless we also had prior knowledge that some of the windows on level two were readily accessible from an abutting fire stair.

4.6.1 How to use an old solution?

If the retrieve and rank case processes have returned the most similar case to our new redesign input problem, there should be a relevant prior redesign solution now available for reuse. However as previously discussed there may be a number of features that differentiate the case that was recalled from the new redesign context, meaning that it is unlikely that the redesign solution can be reused as is without some form of adaptation. The most simplistic computational adaptation operations include feature tweaking such as parameter adjustment and/or value substitution, both of which require specialised domain knowledge. Calculations require knowledge of functional dependencies while copying values across automatically requires mapping knowledge. Asking the user to carry out the operations switches the knowledge burden from computer to human and is the fallback where the domain knowledge is poorly understood and/or very complex.

In a redesign case, when we talk of a redesign solution, this includes any aspects of the original design components that required transformation in order to fit the new requirements. Figure 4.6 illustrates a basic transformation model as proposed by Maher (1990). Making transformation knowledge available for direct reuse should theoretically reduce the amount of first principle reasoning normally required by an adaptation process. Additionally, the ability to recall previous transformation solutions could simultaneously alert a user to the compositional subsystems likely to be affected and the type of adaptation previously undertaken.

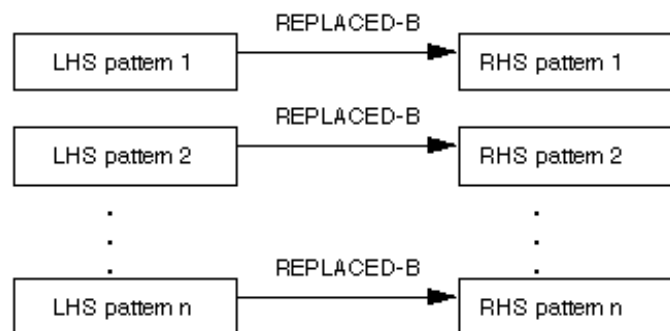


Figure 4.6: Transformation model (Maher, 1990, p. 55)

In the new redesign model, there are six types of transformations that can be employed to reuse cases and these have been articulated as typical CBrR operations. Redesign transformation operations are of three types; the first operating using simple actions on concrete components at the *value* level, the second operating using simple actions on concrete components at the *feature* level, and the third, a more complex set of operators acting on compositional structural relations at sub-component system levels. All three sets of operators are defined as follows:

Component values transformed

- ▶ *Substitute* – replaces an existing feature or features by using value substitution. For instance, this type of transformation signifies that the value of a component feature was *substituted*, which requires that a new value be inserted into an existing component attribute for a feature within the case. An example from the building domain might be when a house is repainted and the colour changes or a door handle is replaced, a handrail height is altered, or a power outlet is repositioned.

Component features transformed

- ▶ *Add* – increases the number of sub-component case features by one or several. For instance, this type of transformation signifies that a feature was *added* where none existed before, this requires that a new attribute-value pair be inserted into the case. An example from the building domain might be when an additional component such as a vent or new electrical outlet is added.
- ▶ *Remove* – decreases case features by taking away, dispose of, or getting rid off case features singly or multiply. For instance, this type of transformation signifies that a feature that previously existed was *removed*, and requires that an attribute-value pair be deleted from the case. An example from the building domain might be when a doorway is bricked in and thus the door as a feature is removed.

Compositional structures transformed

- ▶ *Repair* – mends, fixes or restores component subsystems. This is achieved by repairing composition and decomposition pathways in compositional systems when component features are added or removed. For instance, this type of transformation signifies that the related system components that are connected are also affected. An example from the building domain might be when a doorway is removed and the wall it is connected to must be *repaired* or when a new power outlet is added and the wiring must be *reconnected*.
- ▶ *Relocate* – changes an existing feature or feature subset by taking them out of their existing place, position and/or relationship. For instance, this type of transformation signifies that some components relations are preserved while some are deleted. Removing a sub-component and its set of component features and then adding them to another part of the compositional system achieve this. An example from the building domain might be when a compositional system such as a toilet system (pan,

cistern, lid, flush mechanism etc.) are deleted from an existing location, and are then reused but in a different location say in another room or on another level etc.

The most simplistic method of facilitating redesign case reuse requires user-directed changes to feature-value sets from the *retrieved cases* previously selected by a user. The user then makes changes to feature value sets until all the features and values have been modified to suit the new context. This reuse process is illustrated using pseudo code as follows:

```
Reuse case
begin
    for each {feature(i); value(i)} set in a retrieved case selected by the user or for any user added
    feature(i)
        ask the user for new value(i)
    until    the value(i) of each feature(i) is full
    unless   the user deletes a {feature(i); value(i)} set
    then     copy all {feature(i); value(i)} into case memory and
            then index-case and case-pieces;
end
```

Redesign adaptation requires both simple and complex operators and clearly differentiating and describing them provides a means of communicating adaptation actions regardless of the manner of action i.e. computer or human user. Simple operators carry out simple actions on attribute-value pairs at the most concrete level of an abstraction hierarchy but actions that are more complex are required if the structure of an attribute or sub-component alters. When feature or attribute transformations are carried out, structural decomposition and compositional transformation often follows.

Additionally, the sequence of operations goes from concrete to abstract. Since redesign commences at concrete levels, the adaptation process commences with value transformations followed by feature or attribute transformations. To be most beneficial, all operators must be clearly defined and be sufficiently descriptive to encompass all the redesign actions needed to integrate the new requirements into an existing design description. They must also be capable of clearly distinguishing the type of action or actions required.

The new model of redesign makes transformation actions explicit by storing them for later recall and reuse. Explicitly defining solution classes enables labelling of redesign solution features in a manner that makes the adaptation operation knowledge transparent and thus available for case-based reuse. Redesign transformation actions uniquely contribute to case-based functionality by storing adaptation knowledge in the case library for future recall. CBrR thus has the ability to recall case-based adaptation solutions and reuse them as the primary adaptation method unlike typical CBdR adaptation approaches, which rely on encoding domain knowledge in the form of rules.

Manipulating the existing object description in a piecemeal fashion enables greater flexibility by enabling recall of object descriptions from more than one case. This would enable a piece of a previous case to be reused out of its original context. For example, a particular set of related objects such as a *hand-held shower hose system* (i.e. hose, shower head, controls and wall attachments) might be copied from a previous case and reused in the new case. This method of facilitating redesign case reuse is illustrated using pseudo code as follows:

Relocate case-piece

begin

```
  get {feature(i); value(i)} case-piece input from user for the set of redesign requirement
  features ( $C^p$ ) or the set of redesign object features ( $C^d$ ) to be matched and relocated
    for the {feature(i); value(i)} selected;
      find the list of case-part labels associated with the attribute(j)
      from the case-part indexing list;
    if the list of case-part labels is not empty
      for each case-part(i) in the list of case labels
        assign a similarity value to the case-part(i)
    then if case-part(i) is not in the retrieved-cases
      then add the case-part(i) into retrieved-cases;
    then for each {feature(i); value(i)} set in the retrieved case-part selected by the user
      copy all {feature(i); value(i)} sets into case memory and
        then index-case piece;
```

end

The downside of enabling a user to reuse case-pieces out of context is that they must be modified to suit the new context before they can be acquired and this modification knowledge needs to be stored. The pseudo code for case-piece reuse is similar to case reuse, the main difference being that case-pieces are edited separately.

Edit case-piece

begin

```
  for each {feature(i); value(i)} set in a retrieved case-piece selected by the user or for any user
  added case-piece feature(i)
    ask the user for new value(i)
  until   the value(i) of each feature(i) is full
  unless  the user deletes a {feature(i); value(i)} set
  then    copy all {feature(i); value(i)} into case memory and
          then index case-piece;
```

end

4.6.2 Case acquisition in a CBrR system

CBR improves as cases are acquired because the cases represent knowledge in context. As in all case-based applications, case acquisition involves both capturing the new case for later reasoning and indexing case features. As previously discussed, the new model of redesign differs from CBdR in that indexing involves encoding any new redesign requirements (C^p)

and the set of existing design features (C^d) where they correspond with the redesign solution description features (C^{rs}) in the new case. The new model of redesign does not affect the process of case storage, which can be as simple as copying and pasting the newly solved case from the temporary user interface store and saving it into the long-term case memory store. However, the new model of redesign results in substantially different knowledge being learnt. In the new model of redesign, case acquisition, enables capturing of the adaptation knowledge in addition to new requirements and existing design product features as part of the acquisition process.

The procedure *add-case* copies a new case into case memory. Each feature-value pair is checked initially for completeness. When no values remain empty, then copying commences and the procedure *index-case* is simultaneously run. This process is computationally illustrated using pseudo code as follows:

```
Add case
begin
  for each {feature(i); value(i)} set in case
    if the value(i) of all feature(i) sets is full
      copy all {feature(i); value(i)} sets into case memory and
      then index-case;
    else
      ask user for value(i) of the feature(i)
      proceed until all listed case attributes(i) have a value(i)
      copy all feature(i)-value(i) pairs into case memory and
      then index-case;
end
```

4.6.3 Advantages of a case-based redesign model for redesign reasoning

The new model of redesign as articulated has three major advantages. First, when we acquire a design case in a CBdR system, all the integration knowledge gained in the process of reusing is lost because the process of case acquired stores only the input problem and the new solution. However, the new CBrR model automatically captures adaptation knowledge as a part of the redesign case structure. Second, creating a product representation model for CBrR that separates new requirements and existing design products facilitates recall because the most relevant solution will always be the solution that has features of both the new input and the old design case. Third, articulating and encoding adaptation knowledge so it can be reused facilitates understanding of adaptation and enables copying of prior adaptation strategies, thus reducing the amount and complexity of adaptation processing required. Table 4.9 illustrates the key differences between CBdR theory and the new CBrR model outlined.

Table 4.9: Case-based design versus case-based redesign

	Case-based Design	Case-based Redesign
Starting point	Conceptual design query	Artefact redesign query
Case representation	Problem (concept) Solution (design)	Requirement (problem) Object description ('as found' product); and Solution (adaptation steps).
Browsing	Some structuring of cases using design prototypes, graphical summarisation of cases and/or hierarchical artefact class models.	Transparent structuring of cases using design prototypes, graphical summarisation of cases and the three case contents categories including artefact, new requirement and redesign solution class models.
Recall	<i>Indexing</i> needs to capture critical design domain features. <i>Retrieval</i> is on the basis of a match between the new query and the existing design case-base <i>Ranking</i> depends on the ordering of cases regarding quantity and quality of matches.	<i>Indexing</i> needs to capture critical artefact features at new requirement and existing design description levels particularly where the existing design description components have been modified as a part of the CBrR process. <i>Retrieval</i> depends on the matching of features derived from the new requirements and the original design description with an indexing list containing features corresponding to features of redesign solutions. <i>Ranking</i> depends on ordering cases regarding quantity and quality of matches initially by strong matching (C^p and C^d) and if this fails by weak matching (C^p or C^d).
Adapt	Aspects of existing solutions are changed to fit new problem parameters. Cases are decomposed and recomposed in a abstraction hierarchy starting from the most abstract and working down.	Aspects of redesign solutions are changed to fit new parameters using redesign adaptation operators. Cases are decomposed and recomposed in a abstraction hierarchy starting from the most concrete and working up.
Learning	Initial case query and solution are stored as part of the case acquisition process	Knowledge of transformation actions are stored in addition to new requirements and existing design product features as part of the case-acquisition process. This happens automatically when a case is reused.

4.6.4 Implications for domain specific application

The examples provided throughout this chapter have demonstrated the generic aspects of the CBrR process as applied to less complex (spoons) and more complex (buildings) artefacts. In addition, the differences between traditional CBdR and the new CBrR model mean that the representation of case contents that are required for recall, adaptation and learning processes will also differ.

The application domain of this thesis concerns redesign of buildings for people with disabilities. Redesign in this domain usually follows change in artefact requirements primarily related to change in ability status of the primary user or user group not functionality of the artefact *per se*. All existing design systems assume that functionality can be sufficiently

incorporated within artefact descriptions, often by generalising about user expectations or requirements. However, redesign for people with disabilities depends on being able to relate human ability to building artefacts. This means that CBrR input and output concerning building artefacts for people with disabilities must adequately capture the full lexicon or vocabulary specific to features of buildings that connote access or barriers to accessibility and that capture the full range of human ability.

Table 4.10 illustrates the correspondence between the new CBrR model and what representation structures that will be required of a ontology applicable to the sub-domain of building redesign for people with ability impairments.

Table 4.10: The implications of a CBrR model on modelling of redesign for people with ability impairments

	Case-based Redesign	Domain implications
Starting point	Artefact redesign query	Requires knowledge of human impairment, as knowledge about an artefact in terms of accessibility without knowledge about user ability is insufficient to adequately frame the query.
Case contents	Original design (product description), new requirement (problem), Redesign (product description) and redesign solution (transformation actions).	Requires the articulation of a knowledge intensive representation structure that explicitly captures and/organises all the components into features (i.e. attribute-value pairs) relevant to redesign of accessible buildings for people with disability. Thus it also requires the extension of the CBrR model to include a representation structure that captures the full range of human abilities.
Browsing	Transparent structuring of cases using design prototypes, graphical summarisation of cases and the three case contents categories including artefact, new requirement and redesign solution class models.	Requires the articulation and inclusion of class models for accessible artefacts, new accessible requirements and redesign solutions classes. It also requires the extension of the class model structure to include an additional class model encompassing knowledge of disabilities.
Recall	<i>Indexing</i> needs to capture features at new requirement and existing design description levels. <i>Retrieval</i> depends on the matching of features derived from new requirements and/original design description with an index corresponding to features of redesign solutions. <i>Ranking</i> depends on ordering cases regarding quantity and quality of matches initially by strong matching (C^n and C^d) and if this fails by weak matching (C^n or C^d).	Indexing, retrieval and ranking in CBrR require that the knowledge intensive representation structure used for accessible building artefacts can be related to a range of human abilities. This requires the extension of the CBrR model to accommodate user ability.
Adapt	Transformation knowledge is applied to alter a prior case to fit new redesign parameters. Cases are decomposed and recomposed based on the most relevant concrete features.	Requires articulation of how features are related.
Learning	Transformation knowledge is stored in addition to new requirements, redesign and existing design product features.	Requires the extension of the CBrR model to include the domain of accessible buildings and the range of human abilities.

From reviewing the table, it becomes apparent that the major issues for implementation are articulation of the lexicon or vocabulary in terms of ability to capture and reason with case contents and in extending the CBrR model to explicitly include human ability.

4.7 Reflexive Summary

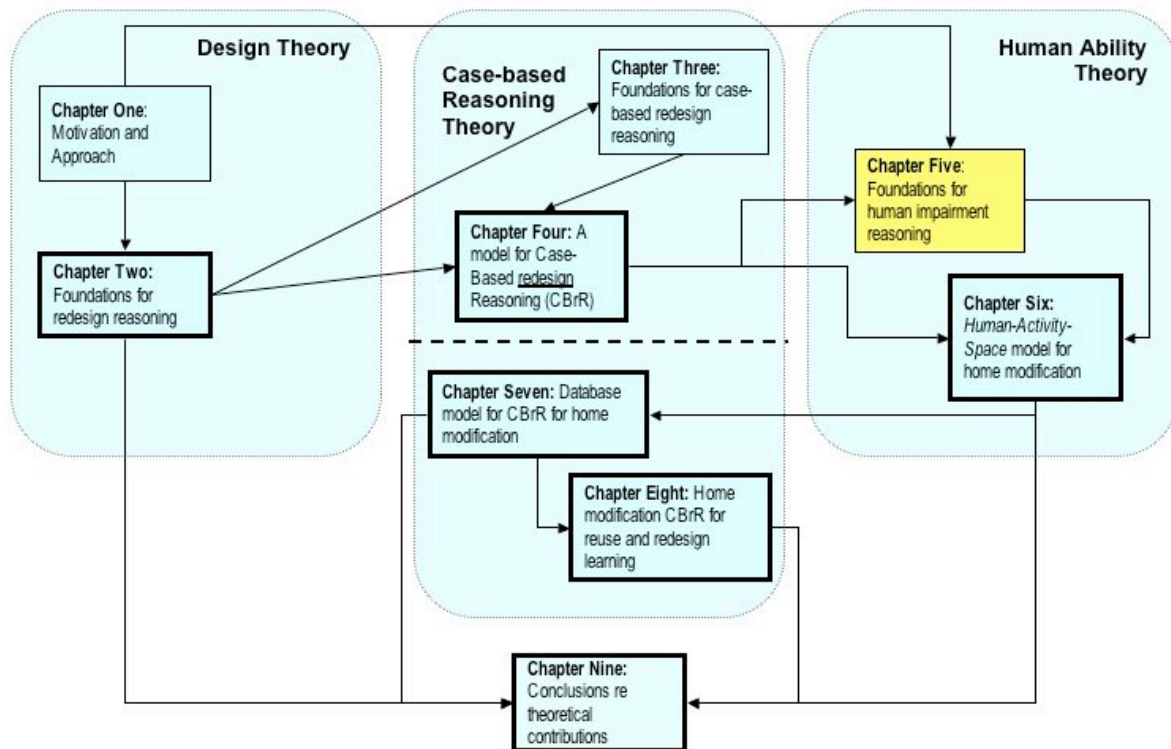
This chapter has explored *how case-based redesign reasoning might be modeled* and has, as a consequence, laid out the process of case-based redesign reasoning and representation to illustrate the differences and advantages of CBrR in terms of recall, adaptation and learning. Specifically the modelling structure started with the general task model and articulated knowledge of redesign goals and problems as follows:

- ▶ the CBrR general task model has as its goal the integration of new requirements with an existing design product description or artefact representation;
- ▶ the problem is composed of both the new requirements and the existing artefact description ; and
- ▶ the solution is composed of the redesign solution description.

This chapter provided the basis for articulation and illustration of the new CBrR model. The CBrR model presented is a unique problem solving method based on CBR whereby:

- ▶ commencement involves evaluation of compositional organisation not analysis or formulation;
- ▶ structured browsing of case contents requires articulation of artefact (i.e. both original and redesign products), the redesign requirement and redesign solution type classes;
- ▶ the indexing and retrieval process reflects the new redesign case formalisation;
- ▶ matching involves both a restriction and a refinement of the standard similarity evaluation function;
- ▶ recall of a redesign solution enables prior adaptation knowledge to be reused as the primary adaptation method; and
- ▶ case acquisition involves substantially different knowledge being learnt.

5



Foundations for human impairment reasoning

Chapter 5: Foundations for human impairment reasoning

5.1 Introduction

This chapter sets out to explore: *what aspects of humans with ability impairments (disability) are important for environmental redesign?* This is a critical question as the domain of application is home modification, a redesign sub-domain where the sole purpose of redesigning an individual's home is to compensate for human ability impairment. In this chapter, human features are articulated so that a relevant computational ontology can be developed for capturing this knowledge in redesign cases.

This chapter presents the current conceptual basis for representing human ability and for understanding how built environments either enable or disable individuals depending on their abilities. It explores how best to represent knowledge about human ability including the widest ends of this spectrum (e.g. people with disabilities). Furthermore, the foundations for representation of ability must be consistent with current domain thinking for them to be effective within case-based redesign modelling.

Explicit representation of human ability facilitates redesign reasoning by enabling the framing of problems and solutions based on relevant compositional and relational understandings. This approach differs significantly from general design practice, which assumes average or *normal* human abilities. Chapter two argued that redesign was different to design and that development of modelling tools capable of reasoning about compositional systems facilitate case-based redesign reasoning.

In any redesign process that is responsive to human ability and that encompasses all persons, including those with disabilities, having an ontological framework capable of capturing human ability becomes crucial. This is because redesign of buildings often stems from a perceived mismatch between the original design in its built form and the actual functional capacities of the human user who occupies it. Thus articulation and understanding of the domain model component assists an understanding of the impact on the development of a case-based redesign application. A domain model makes explicit knowledge dependent task definitions by demonstrating refinement of problem-solving methods.

5.2 Chapter structure

This chapter is structured into a number of parts dealing with issues and models pertinent to developing an ontology suitable for redesign for people with human ability impairments.

First, the conceptual foundations for understanding and describing disability and ability representation are explored. Previous conceptualisations are presented and the resultant shortcomings are highlighted in the context of design and redesign computational modelling.

Second, the chapter explores activity in relation to environmental transactions to draw out theoretical implications regarding how environments enable or disable human ability. Third, it identifies research issues associated with representation of the dynamic and transactional nature of human and environmental feature sets required by case-based redesign reasoning system. The review of human response modelling enables the development of an ontological model for human response suitable for a case-based redesign tool in terms of representation and navigation issues.

5.3 Human impairment and human ability

To talk of people with disability is to talk of a particular subset of a population who are considered to have needs exceeding average or normal population profiles. Implicit in disability definition is the notion of a particular level and type of impairment entitling a disabled person to support either via legislation or compensation structures (i.e. financial, social and/or environmental). Table 5.1 presents commonly held and understood means of both qualifying and defining *disability* and *ability*. The word *disability* has the prefix ‘dis’ implying distance or opposition to the stem word, which is *ability*. Human *ability*, on the other hand, concerns qualities, skills and attributes that suffices to enable actions necessary to human function and which determine quality of life.

Definitions of ability and disability are problematic because they are arbitrary to purpose, which typically delimits or restricts reward and eligibility criteria. Application of these terms typically acts to exclude rather than include. For instance, when a particular department or service makes a judgment regarding an individual in terms of eligibility or ineligibility based on ability criteria. Judgements about ability act to restrict privileges such as income, education, housing or licensing. Other issues include an implicit bias in focus on human attributes in combination with a failure to adequately consider how environmental context shapes human ability. In developing a redesign model suitable for application to the field of human ability, the relations between environmental context and human functionality must be made explicit and must be inclusive rather than exclusive for the widest possible application.

Table 5.1: Comparison of disability and ability definition taken from online sources

Disability Definitions	Ability Definitions
<ul style="list-style-type: none"> ▶ A physical or mental impairment that substantially limits one or more major life activities, a record of such impairment, or a perception of such impairment (www.asu.edu/aad/manuals/acd/acd002.html). ▶ An inability to substantially perform the duties of the member's job by reason of physical or mental impairment determined to be permanent or of an extended and uncertain duration (www.calpers.ca.gov/gloss/gloss.htm). ▶ A person that has a physical or mental impairment that substantially limits one or more major life activities, has a record of such impairment, or is regarded as having such an impairment. Major life activities means functions such as caring for one's self, performing manual tasks, walking, seeing, hearing, speaking, breathing, learning, working and receiving education or vocational training (ADA 1990; www.mrgbec.org/pages/definitions.html). ▶ Any restriction or lack (resulting from an impairment) of ability to perform an activity in the manner or within the range considered normal for a human being (WHO; www.deha.org/Glossary/glossaryd.htm). ▶ The inability to engage in substantial gainful activity by reason of any medically determinable physical or mental impairment that can be expected to result in death or can be expected to last for a continuous period of not less than 12 months (www.ssa.gov/statistics/ssi_annual_stat/2001/glossary.html). <p>A condition that curtails to some degree a person's ability to carry on his normal pursuits. A disability may be partial or total, and temporary or permanent (www.insweb.com/learningcenter/glossary/gener-al-d.htm).</p>	<ul style="list-style-type: none"> ▶ The quality of being able to perform; a quality that permits or facilitates achievement or accomplishment (www.cogsci.princeton.edu/cgi-bin/webwn). ▶ The capacity to do something; the power to perform (standards.nctm.org/Previous/assstds/Glossary.htm). ▶ The present capacity to perform a physical or mental function (www.wmich.edu/evalctr/ess/glossary/glossary.htm). ▶ A characteristic that is indicative of competence in a field (www.wrightslaw.com/links/glossary_assessment.htm). ▶ The quality or state of being able; power to perform, whether physical, moral, intellectual, conventional, or legal; capacity; skill or competence in doing; sufficiency of strength, skill, resources (www.bootlegbooks.com/Reference/Webster/data/4.htm). ▶ A generic mental or physical power such as communication and problem solving which provides the means of performing tasks in a learning, work or everyday situation. (www.ee.wits.ac.za/~ecsa/notes/glossary.htm). ▶ Sufficient mental or physical strength, energy, dexterity, or other attributes and resources to perform job responsibilities and duties (www.michigan.gov/printerfriendly/0,1687,7-147--18616--00.html). ▶ A quality that enables an individual to perform an act, solve a problem, or make an adjustment. (www.childrenwithchallenges.net/definitions.html). ▶ Competence in doing; natural aptitude or acquired proficiency (freire.cascadia.ctc.edu/eportfolioweb/glossary.html). <p>This refers to a talent, such as manual dexterity, visual or spatial acuity, or conceptual thinking. (www.chrpanada.com/en/phaseiiireport/glossary.asp).</p>

Note. The online addresses provide specific dictionary and glossary source information. The table illustrates the range of semantic understanding involved, variation stemming from domain interpretation versus everyday or common usage.

In addition, the pressure to identify and remove architectural barriers to access for people with disabilities has markedly increased following community recognition that all people share the same rights (Goldsmith, 1997; McAuley, 1993). Recognition of these rights is reflected in recent changes to Federal legislation, such as the Disability Discrimination Act of Australia (DDA-1992). Australia just being one of many industrialized nations to enact this type of legislation; similar legislation exists in many other countries including the United States of America and England.

5.3.1 Disability as a concept

The concept of disability traditionally implies a focus on deterioration or deviation, not on the full spectrum of ability and/or enablement (Chiriboga, Ottenbache, & Haber, 1999). Despite failure to include disability within the wider spectrum of human ability, a significant and increasing percentage of the population at large experience functional limitations as a direct sequel to occupational health injuries, home accidents, road trauma, crime, genetic predisposition or inheritance, and/or the onset of chronic disabling conditions associated with the ageing process.

Determining the exact number of individuals with disabilities or limitations due to ageing is not an easy or precise task. Reasons may include older people do not want to be socially stigmatised or to be thought of as disabled and people who are employed or are productive despite significant functional impairment also do not consider themselves *disabled*. In reality, estimates vary depending on the definition of disability employed and the sources of the data with direct consequences for those whom within society are considered to be either enabled or disabled (Goldsmith, 1997).

The difficulty of definitions and labelling aside, in 2003 an estimated 3.6 million people, or 20% of the Australian population were classified as having a disability (Australian Bureau of Statistics, 2004). This is similar to data from other developed countries, such as the United States, that indicates 20.3% of the population have disabilities (Czajka, 1984). Furthermore, it is apparent from surveys over the last 20 years that the incidence of disability is increasing. In Australia, the difference between the 1993 and the 1998 Aged and Disabled Carers survey, indicates that the percentage of the population with a disability increased by 1-2% over this period.

According to the Australian Bureau of Statistics (1998), over a million people had a profound or severe *core activity* restriction i.e. in mobility, self-care, communication etc. Moreover, the difficulties faced by older persons with disabilities are compounded by other factors including the fact that more elders are now living alone without the assistance they might receive from a spouse or other partner (Bridge, Kendig, Quine, & Parsons, 2002b). In fact, consumers, families and healthcare professionals agree that appropriate consideration of physical environments can be a critical factor in reduction of institutionalisation and in promoting integration and inclusion (Iwarsson et al., 1998).

Disability has often been set apart as a special subset of design and therefore of lesser importance for design in general. However, disability is a common condition, and more pervasive than many people realize. Most human users of the built environment experience

disability at some point across a lifespan, even if only temporarily (Jones et al., 1998). Disability is a normal part of life trajectories (Hasselkus, 2002). Redesign for people with disabilities affects a significant amount of the population and is a fundamental determinant of life quality for those affected. A major redesign goal remains the provision of environments that support function. In this sense, environments become prosthetic and are best when they support individual function but do not disable other users (Regnier, 2003). In rehabilitation practice, the environment has been conceived of as a prosthetic support for functional independence (Pynoos, Nishita, & Perelman, 2003; Steinfeld & Danford, 1997).

Moreover, understanding person-behaviour-environment relationships has become particularly important following the recognition that individuals are not inherently disabled but that disability “is the interaction between disabling conditions of an individual and the environment” (Brandt & Pope, 1997, p. 5). Environment as a central determinant of disability replaces earlier more deterministic models, which viewed pathology and the experience of disability interchangeably (Green, 2001). The current understanding conceives of the enabling-disabling process as the *fit* between the person and their environment. *Fit* in this context is how a specific environment frames the individual. This framing process is illustrated in Figure 5.1. As can be seen from the diagram, a person who does not have a disability (a) ‘fits within the square’ and so is fully integrated into society but an individual with a disability (b) does not ‘fit the square’.

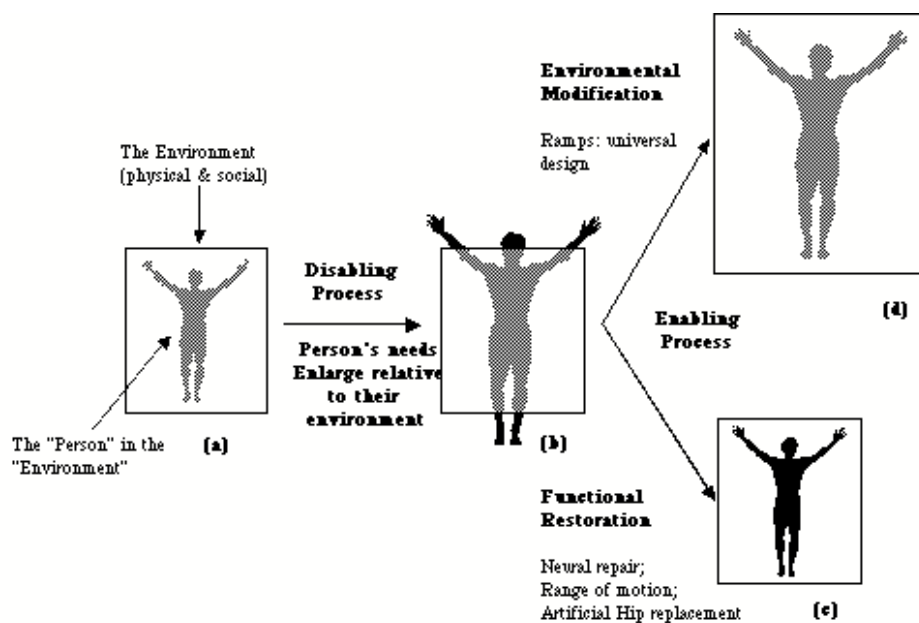


Figure 5.1: Enabling-disabling process (Brandt & Pope, 1997, p. 4)

For instance Table 5.2 illustrates some enabling and disabling factors that cannot be accounted for in the artificial or constructed environment out of the context of consideration of site or geographical locality data. However it is important to note that in this conceptual

view environments are conceived of much more broadly than simply a collection of relevant artefact features and include relevant societal factors as well.

Table 5.2: Enabling and disabling factors in physical environments (adapted from Brandt & Pope, 1997)

Matrix	Natural	Built environment
Enabling	Dry climate Level terrain Clear paths	Ramps Lighting Signage
Disabling	Snow and ice Rocky terrain Sand Gravel High humidity	Steps Low-wattage lighting Absence of alerting system i.e. Auditory, Braille, flashing light etc.

While there is no doubt that the degree and type of disability variation experienced by humans makes for a vast terrain, it is also true that ability is a product of physical environments. For humans the presence of any functional and/or anthropometric irregularities in conjunction with a *disabling* environment results in individuals being unable to carry out activities with the following loss of functional abilities:

- ▶ adequately process visual information;
- ▶ adequately process auditory information;
- ▶ tolerate environmental toxins;
- ▶ adequately process tactual information;
- ▶ communicate in native languages;
- ▶ maintain alertness;
- ▶ maintain physical stamina over distance or during long waiting periods;
- ▶ use hands or arms;
- ▶ grip or hold small objects;
- ▶ balance and control coordination;
- ▶ use feet or legs, and
- ▶ orientate in unfamiliar surroundings.

5.3.2 Human ability and environment theory

Building redesign that stems from human users' needs requires a framework that captures relevant data and that can relate this in a meaningful way to problem solving. All currently accepted theoretical conceptualisations in the social and disability domains present a dynamic transaction between both the person and their environment (Cronberg, 1975; Lewin, 1951;

Sommer, 1969; Steinfeld & Danford, 1997; Kramer, Hinojosa, & Royeen, 2003). The dynamic transactional nature of current understanding becomes clearly apparent when some of the more prominent person-environment interaction theories are reviewed (see Table 5.3). Transactional and social models of human behaviour have evolved over decades in the fields of sociology, psychology, education and public health (Sallis, Bauman & Pratt, 1998).

While there are significant differences in conceptualisation, all approaches claim that human-behaviour or actions are affected by environmental variables. Furthermore, they propose that relationships between person and environment can be articulated and measured. However, while the existence of a relationship between person and environment appears strong, the exact nature of causality still remains unclear (Stark, 2001). The relations between person and environment in most theoretical approaches appear to be mediated by behaviour and/or *activity* responses but the type, degree, directionality and quality of person-environment relations remain loosely specified and unproved. This overview of theory is presented in Table 5.3 so that the reader can understand the importance and relevance of this part of the thesis contribution.

Table 5.3: Review of current person-environment models

Theory	Key concepts
Ecological approach (Bronfenbrenner, (1986)	<ul style="list-style-type: none"> ▶ Four major levels of environmental contexts are: microsystem, mesosystem, exosystem, and macrosystem. ▶ Bi-directional influences between person and environment. ▶ Potential exists for qualitative and quantitative change.
Environmental congruence (Kahana, 1975)	<ul style="list-style-type: none"> ▶ People search for environments that best meet their needs. ▶ Environments vary. ▶ Importance of congruence when environmental options are limited. ▶ Focuses on individual differences.
Environmental press (Lawton, 1985; Nahemow & Lawton, 1973)	<ul style="list-style-type: none"> ▶ Behaviour (e.g., activity performance) is a joint function of the person and environment. ▶ Adaptive functioning occurs in an environment. ▶ Press is the balance between a level of competence and environmental stressor (i.e. the less ability a person has, the more impact the environment will have).

Theory	Key concepts
Environmental stress (Lazarus & Cohen, 1977)	<ul style="list-style-type: none"> ▶ Stress related behaviours are neither a characteristic of the person, nor a response but stem from the relationship between environmental demand and a particular individuals ability to cope. ▶ Stress occurs when the demands of an environment exceed the person's ability to cope (i.e. if coping abilities are inadequate--stress may occur).
Lifespace or field theory (Lewin, 1951)	<ul style="list-style-type: none"> ▶ Behaviour (e.g., activity performance) is a function of the field that exists at the time the behaviour occurs, ▶ Analysis begins with the situation as a whole from which are differentiated the component parts, and ▶ The concrete person in a concrete situation can represented mathematically
Multiphasic environmental framework (Moos, 2002)	<ul style="list-style-type: none"> ▶ Settings of a particular type may vary in supportiveness. ▶ The quality and interdependence of relationships is a key dimension along which the parts of a particular setting varies.
Person-Occupation-Environment (Law et al., 1996)	<ul style="list-style-type: none"> ▶ The quality of a persons experience, with regards to their level of functioning, is the outcome of the fit between the person-environment-occupation transaction ▶ Not possible to establish causal relationships between occupation, health and wellbeing ▶ Need to learn from each person the occupations (e.g., activities) important for health and wellbeing and how problems might interfere with performance of those occupations.
Transactional perspective (Altman & Rogoff, 1987)	<ul style="list-style-type: none"> ▶ Concentrates on pattern of relations between behaviour (e.g., activity performance) and environment ▶ Behaviour (e.g., activity performance) is viewed as an integral part of the person and their environment. ▶ Person in environment is the unit of analysis ▶ Both person and environment dynamically define and transform each other over time as aspects of physical and social contexts ▶ The unit of analysis is not just the person but also an integration of elements in the environment and the person, resulting in his or her behaviour (e.g., activity performance).
Ecological model of occupation (Dunn, Brown & Youngstrom, 2003)	<ul style="list-style-type: none"> ▶ It is impossible to understand the person without understanding environmental context. ▶ Persons influence context and contexts influence persons.

Note. The references linked to the model title indicate the source information. The table illustrates the range of understandings in currently accepted models of person-behaviour transactions.

Early theoretical work on formalising person-environment theory dates back to the 1950s.

Lewin's classic concept of *lifespace* was defined by the notion of behaviour (B) as being the functional (f) product of both personal or individual factors (P) and the perceived environment (E) (Lewin, 1951). Equation 1 illustrates Lewin's theory expressed symbolically. Important within the formulation is the concept of individual difference.

$$\boxed{B = f(PE)}$$

Equation 1: Lewin's symbolic formulation of the Lifespace concept.

Lewin's equation, while emphasizing the importance of dynamism between representations of the person and environment, still fails to capture the relations and complexity inherent. In

reality the transactional perspective of the person-environment interaction makes separation of dynamic and changeable attributes difficult (Schwartz, 2003). So, even if all salient personal or individual factors and environmental perceptions can be captured and computationally encoded, the considerable variation in range makes any rule-based approach both extremely difficult and unreliable.

Behaviours or *activities* undertaken by individuals can be observed, measured and recorded, but without clear theoretical relationships there can be no content or construct validity and any framework or model that lacks validity will not serve to indicate in any accurate way descriptive, evaluative or predictive features essential to outcome. As Moos and Lemke make clear “currently, we do not have a metric for measuring persons and environments and therefore cannot specify the presence of person-environment congruence apart from either the subject appraisal of the individual or the behavioural and affective outcomes of specific combinations of the environment and individual factors” (Moos & Lemke, 1996, p 3).

For this reason, Weisman and Moore (2003) state that they believe that it is necessary to operationalise, measure and treat variables separately while maintaining the necessary holistic relations. Lawton (1985) believed that this could be achieved by building upon the pattern language proposed by Alexander (1979). In other words Lawton perceived that the best path to understanding dynamic transactions spatio-temporally was to discover regularity using a pattern epistemology employing qualitative and quantitative methods. CBrR applies just such a systemic (neo-programmatic) approach to capturing and understanding the transactional and pattern based nature of human ability redesign.

5.3.3 Environmental design components impacting on ability and wellbeing

Sensory modalities and physical abilities are subject to variation and define both normal ability and any qualifiers of human impairment (Koncelik, 2003). Understanding this variation is central to design that enables function and redesign that enables or provides prosthetic support (Velde & Fidler, 2002). Critical aspects of environments previously identified as being of significance to human ability are as follows:

- ▶ *Lighting and colour*, is critical to the uptake of information and directly impacts cognitive function and way finding (Long, 1995). Adequate lighting is particularly important in mobility for persons with visual loss (Stuen, 1991). On the other hand, colour and light have been shown to impact human cognition (Burrige & Ormandy, 1993; Mood, 1993; Freeman, 1993). For instance, broad-spectrum white light has been applied therapeutically to treat seasonal affective disorders (SAD) and to improve feelings of wellbeing (Hopton & Hunt, 1996), while colour also affects

emotional states (Bell, Greene, Fisher, & Baum, 1996, 2001). Colour can also be used prosthetically to cue persons with impaired cognition (e.g., dementia) (Cooper, 1985).

- ▶ Materials selected for construction and their subsequent combination and arrangement affect *sound quality*. The sound absorbency quality of materials can either amplify and mix sounds creating problems for those with hearing impairments or can act to reduce residual capacity (Koncelik, 2003).
- ▶ *Air quality* can affect lung function, can alter mood and affects the human limbic system. In design for health, ventilation to avoid the build up of toxins and/or musty/stale air is critical for those with reduced or impaired cardio-vascular function (Barnes, 1998; Williamson, Martin, McGil, Monie, & Fennerty, 1997).
- ▶ *Opportunities for positive social interactions*; that is, high contact potential either increases or decreases feelings of wellbeing and indirectly impacts health. In design terms this relates to inclusion or exclusion of communal areas such as a meeting room, shared seating in garden, foyer and laundry areas in residential accommodation (Owen, Rutherford, Jones, Wright, Tennant & Smallman, 1996).
- ▶ *Design to reduce repetitive and/or destructive behaviours*; such as reduce aggression behaviour potential by provision of positive energy outlets i.e. gym area, punching bag etc) and/or design to reduce agitation/wandering i.e. residential housing for dementia provides a good example (Alzheimer's Association Australia, 2000).
- ▶ *Design to address human autonomy and territoriality behaviours*, is also crucial. For instance, if living space is to be shared, one person should not have to walk through someone else's space to access a shower, window etc. (Pedersen, 1997).
- ▶ *Design to address human physiology*. The degree of cardio-vascular fitness, muscle strength, range of motion and flexibility in combination with human factor attributes determines an individual's ability to negotiate complex environments. In design terms this relates to proximity of spaces and the number, degree and type of physiological ranges demanded. For instance fences, walls, high storage, steep stairs and long ramps constrain activity patterns or behaviours and may exceed individual physiological capacity (Iwarsson & Isacsson, 1993; Lilja & Borell, 1997; Reutersward, 1995).

There is general agreement that these environmental qualities are amenable to design and redesign manipulation. The significance of the degree and quality of their consideration in

regard to individual human ability remains largely unknown. As a result, people experiencing limitations often face barriers with undertaking everyday *activities* such as hearing what is said, reading small print, bathing, dressing, climbing stairs or understanding signage. Furthermore, actual manipulation of elements without clear causality or metrics remains problematic. Consequently outcomes are often less than anticipated and difficult, if not impossible, to generalise.

5.4 Disability and anthropometrics (i.e. human measurement)

Human factors or anthropometrics concern the body of knowledge regarding attributes of performance relevant to design (Bradtmiller & Annis, 1997; Koncelik, 2003). Most design has at its basis the assumption of *sameness* that is, that human users are alike in what they expect in terms of building performance (Matrix, 1984). Classicist architectural theory revolves around a conception of the human form that is embodied by a ‘able-bodied’ man (Imrie & Wells, 1993; Knox, 1987; Sennet, 1994). For instance, this type of thinking is embodied in Le Corbusier's modular, which assumes the proportions of an idealized upright healthy male body (Imrie, 1996). In addition, artefacts including architecture and everyday objects have been designed for mass appeal. Thus, much of what people interact with on a daily basis owes more to fashion than to consideration of anthropometrics (Brandt & Pope, 1997). As a result, functional outcomes for people with ability limitations engaging in activities is often problematic and redesign is the norm.

Every individual is unique and as a population grouping, the human species is quite diverse (Dreyfuss, & Dreyfuss-Wilson, 2003). Joe, Josephine and their two children (i.e. austere line drawings of human measurement averages) were developed in the United States in the 1950's as an attempt to address the fact that design for humans had to address the fact that humans come in assorted sizes (Dreyfuss et al., 2003). Because of the degree of variance amongst humans, human factor data is normalised and represented as percentile bands. Percentile bands in this case represent bell-shaped frequencies of population characteristics. Bell-shaped frequencies are characterised by the tail at both ends, representing a minority of individuals who fall at extreme ends of the normal distribution curve. These *tails* at either end represent the extremes for the single body dimension or human feature under consideration. Typical dimensions relevant to building design include height, visual acuity, hearing etc (De Chiara & Callender, 1990; Panero & Zelnik, 1979).

Designers are trained to design for a mythical ‘average’ group of people, but in fact this group does not exist (Panero et al., 1979). No wonder, according to (Koncelik, 2003), that designers generally prefer a view of human factors that allows maximum generalisation across the

broadest range of the population for the development of products, interiors and architecture. Consequently, design guidance in the form of dimensional minima is the norm. Dimensional minima derive from anthropometric collections that are averaged. These averages are then employed to form design purpose specific spatial envelopes.

Figure 5.2 illustrates a generalised or normative model of disability where spatial requirements necessary to undertaking the activity of reaching or manipulating a tap from a wheelchair are presented. Spatial envelopes generally assume normative ability. Thus, as is typical, in our spatial algorithm illustration, it is presumed that the upper limb ability of the wheelchair user remains unaffected.

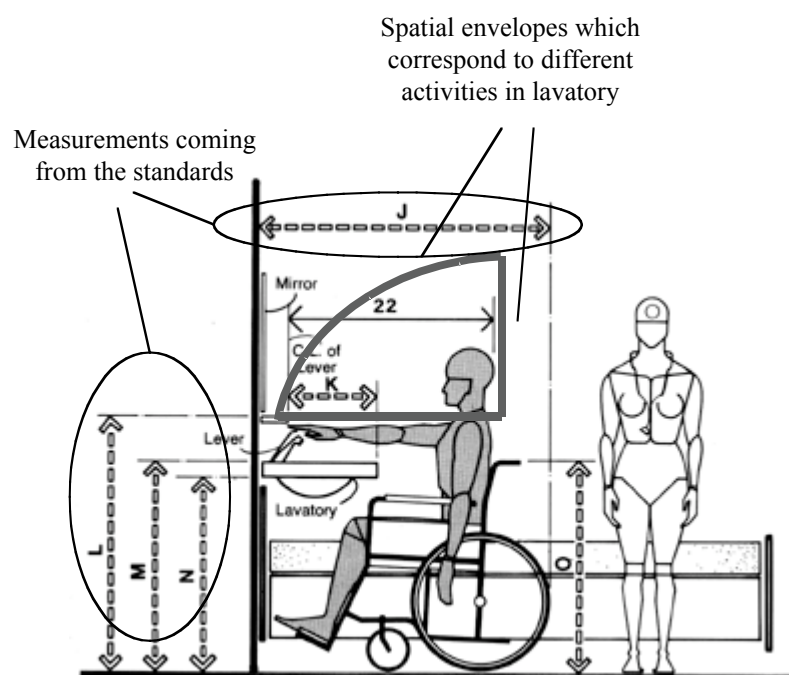


Figure 5.2: Activity requirements are the basis for spatial algorithms (adapted from De Chiara & Callender, 2001, p. 1592)

Nevertheless, people with disabilities are not a homogeneous group and factors, such as sex, age, age of impairment onset, disability type etc. all impact on generalisability of anthropometric data (Australian Institute of Health and Welfare, 2000). Consequently, common anthropometric assumptions fail to hold true for a large number of persons with disabilities, such as those who use wheelchairs for mobility. Individuals with impairments caused by particular health conditions such as quadriplegia, multiple sclerosis, stroke or muscular dystrophy of sufficient severity to require wheelchair usage are more likely than not to lose bilateral upper limb reach as well.

5.4.1 Limitations with representing human function for design

Inclusive design based on anthropometric parameters as recommended by human factor research means trying to accommodate the widest range of percentiles for specific sets of human dimensions (De Chiara & Callender, 1990; Panero & Zelnik, 1979). A common misunderstanding is that design accommodating the widest range (i.e. the 5th or the 95th percentile data) can accommodate everyone including people with disabilities. There are a number of key factors of significance in understanding anthropometric data that make designing for all people, particularly people with disabilities problematic.

First, anthropometric data sets for people with disabilities are either based on small population subsets and may be incomplete (Bradtmitter & Annis, 1997; Diffrient, Tilley, & Bardagjy, 1990) or they exclude people with disabilities altogether (Kroemer, 1987; Steinfeld, Lenker, & Paquet, 2002). Second, because individuals may have more than one disability, it is possible to design a product to include the 95th percentile data and end up with a product that can be used by far less than 95% of the target population (Vanderheiden, 1998).

Third, methodologies for the collection of anthropometric data from people with disabilities are hampered by lack of standardised procedures for measurement particularly landmarking (Bradtmitter & Annis, 1997). Consequently, meta-studies attempting international comparison are impossible because existing body descriptors lack landmark uniformity. This is, in part, because the existence of human impairment widens the potential for variance in body size, posture and function. As Steinfeld et al., (2002) make clear, conventional anthropometry fails in providing data useful for human impairment design. Moreover, effective use of anthropometric data requires not just that the anthropometrics be related to the design but that be adequately descriptive of the intended user to guide design functionality decisions. Thus, most current design depends on anthropometric principles which attempt to accommodate the mythical average person at worst or the 95th percentile person at best and assume uniform reach ranges, limb segment lengths etc. For instance, certain types of disability such as dwarfism may violate principles of assumed regularity in limb segment length with the result that reach calculations cannot be accurately predicted based on normative data. Moreover, the incidence of multiple disabilities such as arthritis affecting posture and reach plus loss of visual acuity commonly occurs within the older population. For this reason classification into subclasses based on disability fails for individuals who have multiple impairments.

Finally, rule or norm-based anthropometric approaches mean that even if human-factor data from older or disabled persons were part of the mainstream design process, it would still never be possible to design so that everybody can be accommodated (Vanderheiden, 1998). This fact alone means that redesign to better accommodate human variance will remain an

issue well into the future. Moreover, because of difficulties associated with capturing the full range of human ability, all computational application to date have codified human response data as either rules in the form of performance criteria or as normative statements of expected responses (Steinfeld & Danford, 1997). Standards as a conceptual model for design for people with disabilities are fundamentally flawed because they assume regularity and fail to capture the complexity of person-environment relationships (Steinfeld & Danford, 1997). Moreover, Australian access standards are not regulatory within building classes 1 and 2 (i.e. residential housing). Additionally, access standards only provide a generalised dimensional minima not the maxima required for optimising individual human performance.

5.4.2 Disability and design

All current computer-aided design programs address human functional requirements as implicit goal related functional constraints. This approach, while reducing complexity, presents difficulties for an effective CBrR system because of the underlying assumption that human factor data can be adequately captured, manipulated, and reasoned about in this manner. Unfortunately, the limitations with this approach are numerous. First, much of the explicit knowledge of disability and the use of terms such as function are not mutually shared or have fundamentally different meanings to different professions. In architecture, for instance the word *function* is only very loosely connected to human performance. Function in architecture is normally interpreted as the ability of materials and structures to perform as expected in terms of general design goals.

Second, human factor data related to design requirements presumes that it can be adequately expressed in normative values as expressed in design guides and standards. Most of the research on the relationship of the built environment to human activity has centred on abstracting data so that it can be encapsulated in building regulations, design norms, and standards. Furthermore, it is only relatively recently that the needs of a wider range of the population, including those with disabilities, have been considered and incorporated in this process (Dodd, 1998). Although, an extensive body of research literature on creation of more inclusive design practices now exists, dispersal across disciplines and cultures in conjunction with lack of guidance on contextual interpretation makes application problematic (Clarkson et al., 2000). As Van deVoordt, makes clear, there is currently no consensus on minimum dimensions because “the measurements recommended in various studies, standards and design guides are widely divergent” (1999, p. 71).

Third, and most importantly from a CBrR perspective, redesign for human ability typically stems from post-occupancy evaluation which reveals mismatches between the actual building design and the abilities of the user which may have changed over time. Human ability results

from genetics, the lifespan or disability and an appropriate redesign response requires both individual and contextual reasoning, which demands a more complete and detailed human factor frameworks to guide reasoning outcomes. It is not surprising, then, that the designed world particularly the construction of buildings rarely, if ever, matches the full range of human responses perfectly. How an individual responds to a particular artefact design cannot be easily grouped into either attributes of the person or attributes of the environment.

Fourth, a design's impact on human ability or *function capacity* can be attributed to a complex interaction between assistive technology (aids or equipment) and architectural design or redesign. The complexity of the relationship becomes apparent when realisation sets in that human ability and redesign are interrelated and in fact interact in both defining the redesign problem and in finding a suitable solution. For instance, the provision of assistive devices, including standard mobility aids (i.e. walking sticks, Canadian crutches or wheelchairs) determines spatial requirements such as the amount of clear floor area required for circulation. Moreover, difficulty carrying out functional tasks such as transferring on/off the toilet can be solved by a variety of means. A redesign solution might involve a non-standard toilet pan substitution to raise the seat height. Alternatively, an assistive technology solution such as a clip on toilet-raising device may enable task completion equally well in the shorter term. Lastly, the preferred solutions might be a combination of redesign and assistive technology provision. The decision framework is typically influenced by contextual factors such as life expectancy, security of tenure, availability, affordability and general condition of "as found" original design features.

5.4.3 Disability as a minimum data set

The International Classification of Functioning, Disability and Health (ICF) provides a framework for the conceptualisation, classification and measurement of disability (Australian Institute of Health and Welfare, 2003). The ICF eschews disability as a descriptor, using instead the concept of activity limitation. Prior to this disability was classified under the International Classification of Impairments, Disabilities and Handicaps (ICIDH) in terms of disease and handicaps (Ustan, 1997). The terms used within the ICIDH (versions 1 & 2) stemmed from medical and health theories and were primarily concerned with capturing changes related to the person. Consequently, environmental aspects were nascent in ICIDH-1 if not completely absent in ICIDH-2. Figure 5.3 illustrates the change in focus between the ICIDH-1 and the ICF.

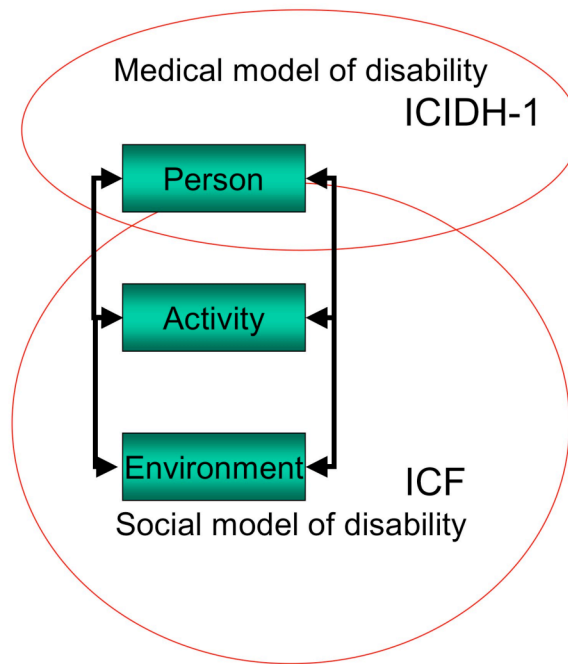


Figure 5.3: Evolution of the ICF towards a social model of human impairment

The inclusion of environmental factors as part of the classification is due largely to the much greater concern about person-environment fit and a understanding of disability where the focus has shifted away from the problems with the person to environmental deficits. The ICF model encodes functional performance of persons with disabilities and makes discussing and/organising the assessment of human impairment related functional performance possible (Mathiowetz, 1993; Lollar, 2003). Moreover, the ICF system provides the most widely used conceptual framework for disability related research (Steinfeld & Danford, 1999).

Prior to the development of the ICF model there had been a systematic failure to consider and capture human diversity (Bickenbach, Chatterji, Badley, & Usten, 1999). Consideration of the built environment and access-related redesign requires a framework that extends the representation of human ability and enables an understanding of the dynamic between individuals and their environments. The ICF framework links impairment and participation using activity as the means for organising information in a meaningful and interrelated way. The interaction of ICF concepts as currently understood is illustrated in Figure 5.4.

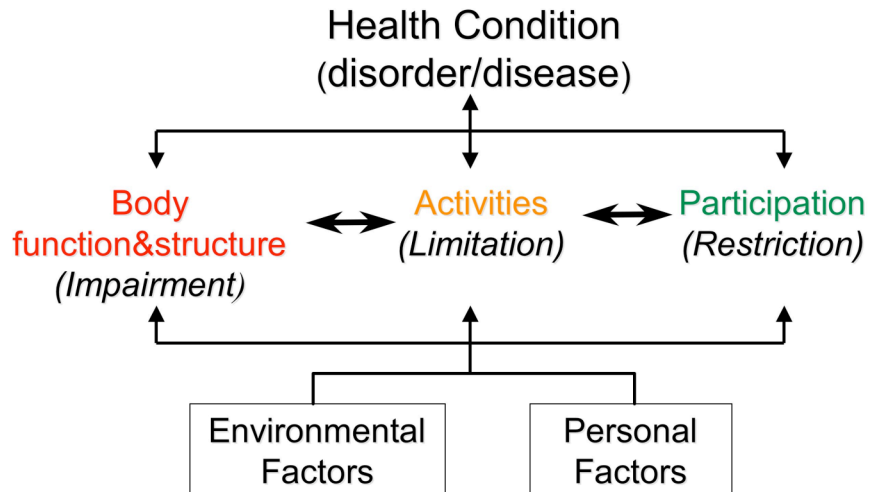


Figure 5.4: Interaction of ICF Concepts (Kostanjsek, 2001, p. 18).

The framework provided by the ICF enables the encoding of variables relevant to transactional theory and includes human ability and activity in the form of capacity and performance qualifiers (World Health Organisation, 2001).

The World Health Organisation (2001) defines the ICF model components as follows:

- ▶ *Body functions* are the physiological functions of body systems (including psychological functions).
- ▶ *Body structures* are anatomical parts of the body such as organs, limbs and their components.
- ▶ *Impairments* are problems in body function and structure such as significant deviation or loss.
- ▶ *Activity* is the execution of a task or action by an individual.
- ▶ *Activity limitations* are difficulties an individual may have in executing activities.
- ▶ *Participation* is involvement in a life situation.
- ▶ *Participation restrictions* are problems an individual may experience in involvement in life situations.
- ▶ *Environmental factors* make up the physical, social and attitudinal environment in which people live and conduct their lives. These are either barriers to or facilitators of the person's functioning.
- ▶ *Personal factors* are contextual influences on function and activity limitation that are intrinsic to the person. They include features like gender, age, temperament, intelligence, social background, education, past and current experiences, personality.

In the ICF classification system each component is decomposed into domains hierarchically. The hierarchy of classification of the domains is outlined in Figure 5.5. However, as a result of its historical development, the ICF is still evolving and a number of the newer areas are

still poorly developed, particularly the contextual factors comprising the newer environmental and personal factors categories.

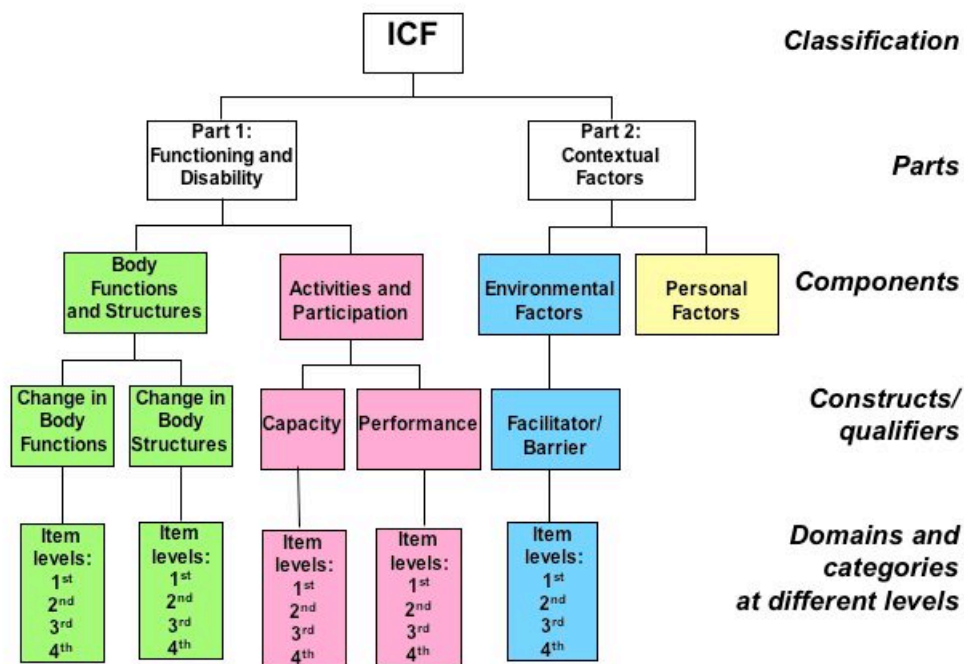


Figure 5.5: Classification hierarchy within the ICF framework (Kostanjsek, 2001, p. 24)

The ICF classification hierarchy divides category codes into two primary domains with both having two sub-category divisions resulting in a standard classification pattern with four item levels. However, while contextual factors are theoretically divided into environmental and personal factors, the personal factors aspect exists at a component level only (i.e. does not have any qualifiers and does not have any formalised domain categories). Furthermore, conceptually it could be argued that personal factors are in fact attributes of an individual and so, if included, should instead be grouped with attributes belonging wholly to a person (i.e. body functions and structures or activities and participation).

In the ICF coding system framework, information is structured into three primary domains: Impairments (I); Activities (A); and Participation (P). The intention of the framework is to represent these domains in parallel and the interpretation guidelines provided state the need to collect data independently for all three domains prior to exploration of causal links or associations (World Health Organisation, 2001). Table 5.4 provides the operational definitions pertinent to the three domains used plus that of a health condition itself.

Table 5.4: Operational definitions of ICF dimensions

Term	Definition
Health Condition	The alteration or attribute of health status of an individual which may lead to distress, interference with daily activities, or contact with health related services; it may be a disease (acute or chronic), disorder, injury or trauma, or reflect other health-related states such as pregnancy, ageing, stress, congenital anomaly or genetic predisposition.
Impairment	Loss or abnormality of body structure or of a physiological or psychological function. Negative aspect of competence in relation to activity performance.
Activity	The nature or extent of functioning at the level of a person. Activities may be limited in nature, duration or quality.
Participation	The nature and extent of a person's involvement in life situation's in relation to Impairments, Activities, Health Conditions and Contextual Factors. Positive aspect of competence in relation to activity performance.

Note. Derived from the World Health Organisation (2001).

The definitions provided are derived from but differ slightly from the definitions provided within the ICF language taxonomy and are thus dissimilar to those in common usage as expressed in dictionary definitions. Because the ICF has evolved away from the medical model towards a social model of disability designed to include all people, not just those with disabilities, encoding regarding any particular disease or health condition has been removed from the coding framework. In health informatics usage these codes are instead generated from the International Classification of Diseases (ICD). In Australia, the version currently in use for health information management coding is ICD-10-AM (2002). Unfortunately this means that there is currently no clearly hypothesised metric for expressing relations between the occurrence and severity of disease as coded within the ICD and the impact on human ability as coded by the ICF.

However for a CBrR in the domain of human impairment, knowledge of health conditions remains important for case-based recall and inclusion enables learning about regularity and potential for generalisability in terms of redesign outcomes. For this reason 'health condition' has been taken from earlier versions and reintroduced to relevant operational definitions which are outlined in Table 5.5. Consequently, utilisation of the ICF model provides a template for ontologically organising data and for case and case-part indexing in an activity and human centred CBrR system.

Although the ICF was developed as a health related classification tool, it has already proven its use as a statistical tool in the collection and recording of data across a variety of domains including insurance, economics, education and legislation. It is of particular relevance to architectural redesign because it classifies "on the one hand 'attributes/experiences' of people and on the other hand the 'situations/circumstances' in which people find themselves" (World

Health Organisation, 2001). Table 5.5, provides an overview of the basic entity dimensions within the ICF framework.

Table 5.5: Basic overview of dimensions in the ICF health classification framework

Dimensions	Impairments	Activities	Participation	Contextual Factors
Level of functioning	▶ Body (body parts)	▶ Person (person as a whole)	▶ Society (relationships with society)	▶ Environmental factors (external influence on functioning) ▶ Personal factors (internal influence on functioning)
Characteristics	▶ Body function ▶ Body structure	▶ Person's daily activities	▶ Involvement in the situation	▶ Features of the physical, social and attitudinal world
Positive aspect	▶ Functional and structural integrity	▶ Activity	▶ Participation	▶ Facilitators
Negative aspect	▶ Impairment	▶ Activity limitation	▶ Participation restriction	▶ Barriers and/or hindrance
Qualifiers	▶ Severity ▶ Localization ▶ Duration	▶ <i>Degree of difficulty</i> ▶ Assistance ▶ Duration ▶ Outlook	▶ <i>Extent of participation</i> ▶ Facilitators or barriers in the environment	▶ None

Note. This synthesis comes from analysis of the World Health Organisation (2001).

The value of presenting concepts in this way portrays a problem solving sequence where intervention or modification of one element dynamically affects other elements. For example, a health condition does not automatically result in activity restrictions. An instance of this is a wheelchair user showering independently. In this case, it is the shower itself, which disables by presenting environmental barriers such as a hob or fittings out of reach range, or alternatively, enables by compensating for dependence on a wheelchair by affording a hobless design and locating fittings within the users' reach range.

The ICF coding framework utilizes an alphanumeric coding system whereby the following denote codes for:

'i' = Impairments of Function

's' = Impairments of Structure

'a' = Activities

'p' = Participation

‘e’ = Environmental Factors

The actual coding system is of interest because the focus on impairments reveals unequal emphasis on domains. For instance, the impairment domain contains separate coding for ‘Function versus Structure’ divisions. To illustrate, a human has a normative mechanical body structure including arm limbs. This enables the extension function used for device manipulation. However, a person with a genetic limb malformation may have an abnormality of limb structure such as a hand growing directly off the shoulder girdle. An abnormality of limb structure limits hand placement and so impacts both the form and the manner that the individual performs the reaching activity.

Human ability concerns the range and type of abilities available to an individual stemming from their unique set of body structures and functions. Body structures are organic and so are removed from their base materials (e.g., bones and joints not carbon dioxide). The quality of bodily functions (e.g., cardiovascular, pulmonary etc.) relies on an integrated and complete system that cannot be achieved by any one part alone (e.g., a heart, lung etc.). Within the ICF body structures and functions underpin human capacity and thus activity performance.

The ICF framework indicates that both personal and environmental factors are significant. However, as previously mentioned, no coding structures currently exist to capture the personal aspects. Moreover, the environmental factors are high level only and are only articulated as they relate to the six sub domain levels as illustrated in Figure 5.6.

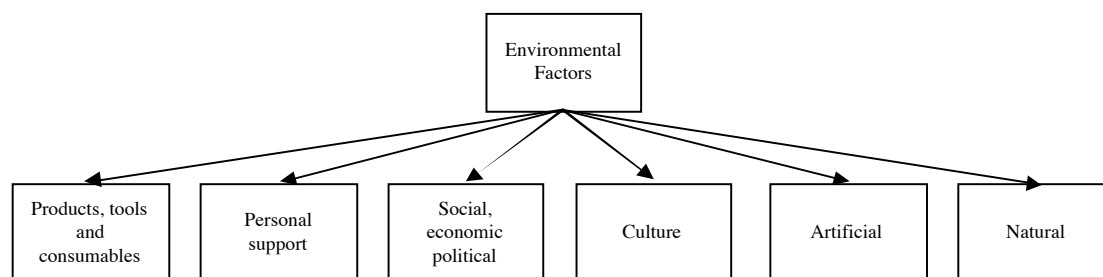


Figure 5.6: Taxonomy of key environmental factors listed in ICF

The current clinical version of the ICF includes 152 categories which are unequally divided into 38 body function codes, 20 structure codes, 57 activity and participation codes and only 37 environmental codes (Classification, Assessment, Surveys and Terminology team, 2002). The complete set of existing coding structures relevant to this thesis out of the ICF coding booklet are provided as an illustration of this point.

1. Products tools and consumables (e00100-e09999)
 - ▶ Money or other assets (e00200)
 - ▶ Assistive technology (e00300)

-
- Aids for personal mobility (e00330)
 - Aids for housekeeping, furnishing and adaptations for homes and other premises (e00340)
 - Aids for communication, information and signalling (e00350)
 - Aids for handling products and goods (e00360)
 - Aids and equipment for environmental improvement, tools or machines (e00370)
 - Aids for recreation (e00380)
 - ▶ Products for personal use in daily living (e00400)
 - ▶ Furniture (e00430)
 - ▶ Household appliances (e00440)
2. Personal support and assistance (e10100-e19999)
- ▶ Family members (e10100)
 - ▶ Friends (e10200)
 - ▶ Acquaintances, peers and colleagues (e10300)
 - ▶ Personal assistant and other care providers (e10400)
 - ▶ Health service providers (e10500)
 - ▶ Animals (e10600)
3. Social, economic and political institutions (e20100-29999)
- ▶ Social assistance programs (e20110)
 - ▶ Social insurance programs (e20120)
 - ▶ Disability and related pension schemes (e20130)
4. Cultural structures, norms and rules (e30100-e39999)
- ▶ Family and kinship (e30110)
 - ▶ Community (e30120)
 - ▶ Formal social rules (e30300)
 - Law (e30310)
 - Regulation (e30320)
 - Customary law (e30330)
 - Religious law (e30340)
 - International law and convention (e30350)
5. Artificial environment (e40100-e49999)
- ▶ Architecture (e40100)
 - ▶ Residential buildings (e40110)
6. Natural environment (e50100-59999)
- ▶ Geography (e50100)
 - Terrain (e50110)
 - Altitude (e50120)
 - ▶ Weather and air quality (e50300)
 - Temperature (e50310)
 - Humidity (e50320)
 - ▶ Precipitation (e50340)
 - Wind (e50350)
 - Air quality (e50360)
 - ▶ Sound (e50500)
 - Noise level (e50510)
 - Sound quality (e50520)
 - ▶ Light (e50600)
 - Sunlight (e50610)
 - Artificial lighting (e50620)
-

The distinction between artificial and natural environments made within the ICF framework requires mention because natural environments can substantially impact the experience of human impairment and the redesign solutions required (Brandt & Pope, 1997). Moreover, natural environmental aspects will interact with the artificial design solutions. For instance, the actual rainfall or snowfall experienced will impact redesign by either relaxing requirements for coverage, heating and drainage or by increasing them. The fact that natural items are better articulated is an advantage of the ICF taxonomy. Some of the advantages of utilising the ICF framework are listed in Table 5.6.

Table 5.6: Advantages of building on the ICF framework

ICF Constructs	Advantages
Human functioning	Not merely disability
Universal model	Not a minority model
Integrative model	Not merely medical or social
Interactive model	Not linear progressive
Parity	Not etiological causality
Context	Inclusive not person alone
Cultural applicability	Not solely western concepts
Operational	Not theory driven alone
Life span coverage	Not adult driven

Note. This synthesis comes from analysis of the World Health Organisation (2001).

Articulation of person-environment fit for people with disabilities requires a framework to capture and segment relevant human factor elements. Any redesign model in the domain of disability requires articulation of individual attributes as they relate to redesign requirements. The ICF model developed by the World Health Organisation (2001) as previously outlined provides such a foundation. The intent of ICF development was to provide a unifying framework for describing the consequences of disease.

The ICF developed from a health foundation so it covers the attributes of humans with limitations fairly comprehensively. However, while environmental aspects remain much less comprehensive the current version stems from extensive discussion with experts and from field trials over ten years. It is therefore, not surprising that it implicitly incorporates many current theoretical notions concerning disability such as *environmental–press* (Lawton, 1985) and *enablement* theories (Brandt & Pope, 1997). Figure 5.7 illustrates how these theories could be seen as mapping on to the ICF and when added assist in describing disability, activity and environments in terms of the full spectrum of human ability (i.e. including both positive and negative influences).

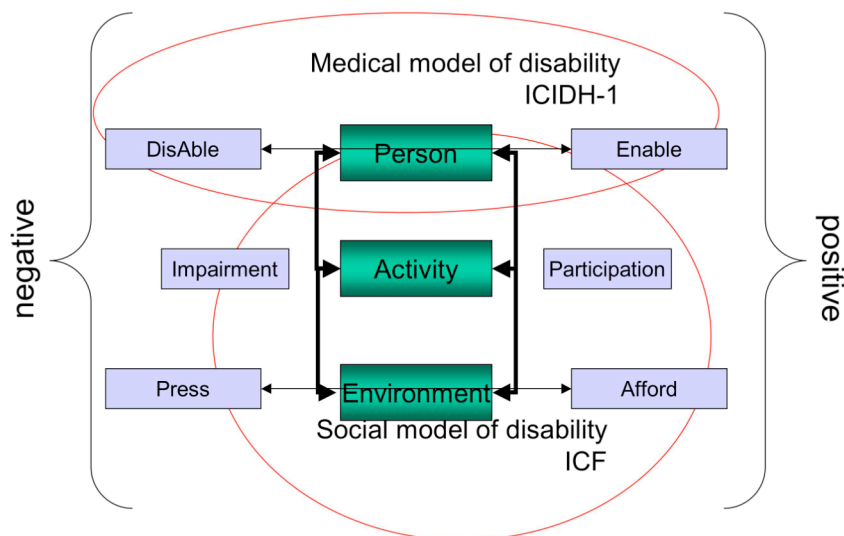


Figure 5.7: Linking the ICF to disability theory

Incorporating the ICF model makes discussing and/or organising the assessment of human related functional outcomes possible (Mathiowetz, 1993). For example, components can be encoded as attribute value pairs. Incorporation of the ICF model within a CBrR dealing with redesign for people with disabilities provides a template for organising human (i.e. person and activity) related data and for case and case-part indexing. The ICF model makes explicit impairments, activities and participation and their relationships. Incorporation of the ICF framework provides a CBrR in the human ability domain with a:

- ▶ unified and internationally accepted standardised language for capturing the aspects of ability resulting from disease conditions;
- ▶ research framework that enables the measurement of the impact of environmental redesign on human functioning; and
- ▶ home modification relevant framework for redesign based problem solving.

However, while the ICF model provides an internationally acceptable ontological framework for collating and encoding data relevant to better understanding the contextual relationships between the built environment and human performance, a number of serious limitations exist to just being able to apply the ICF as is. First, it fails to specify the relationship between person-environment fit. Thus, some method of connecting the person and the designed artefact still requires consideration. Fit may be understood in a dynamic or static sense and if it is to be described non-arbitrarily it needs to be identified and defined.

Second, at this point in time, the fact that the contextual factors in the ICF framework are incompletely specified means that these must be developed separately for this project. Third, the ICF fails to specify environmental spaces and the relationship between components of and

in a space to the space itself. For instance, the ICF classification of environmental component factors does not include toilets or the relation between a toilet space, the toilet pan and the toilet roll holder. Fourth, the ICF is in reality numerical codes used to identify impairment, activity and participation features of a particular person with a disability. Use of numerical codes for home modification practitioners is not a part of existing practice and remains impracticable without access to the ICF codebook. Codes reduce case content transparency to human users and so the semantic labels of concepts and items appear to be of greater practical value. Finally, utilising all the existing ICF item level categories (e.g., particularly some of those relating to domains and categories at different levels of changes in body functions and structures) remains impractical in the home modification application context. Incorporating this level of detail is unnecessary at best and at worst, provision of excessive detail may increase case complexity and coding error. Thus streamlining the original ICF domain components will ensure greater applicability to the domain of home modification cases.

5.5 Human activities

Activities are a central feature of the new conceptualisation provided by the ICF framework. Nevertheless problems exist because of confusion with the notion of participation (Millar, 2002). Participation in the ICF coding structure is in reality an extension of activity and to a large extent remains unclear. Additionally, concern exists that adding on capacity and performance categories might provide meaningless data (Millar, 2002). However, despite these concerns, activities have become increasingly important because measurement of health care outcomes have shifted to the assessment of function at the level of everyday activities. In this sense, *activities* comprise relevant task sets such as opening and closing a door, passing through etc. Table 5.7 presents commonly held and understood means of both qualifying and defining occupation, activity and task. Being able to conceptually distinguish them and to understand that these terms have an implicit hierarchy is important.

Table 5.7: Comparison of occupation, activity and task definition taken from different online sources

Occupation	Activity	Task
<ul style="list-style-type: none"> ▶ The principal activity in your life that you do to earn money (www.cogsci.princeton.edu/cgi-bin/webwn) ▶ Any activity that occupies a person's attention (www.cogsci.princeton.edu/cgi-bin/webwn) ▶ The act of occupying or taking possession of a building (www.cogsci.princeton.edu/cgi-bin/webwn) 	<ul style="list-style-type: none"> ▶ any specific activity (www.cogsci.princeton.edu/cgi-bin/webwn) ▶ the state of being active (www.cogsci.princeton.edu/cgi-bin/webwn) ▶ an organic process that takes place in the body (www.cogsci.princeton.edu/cgi-bin/webwn) ▶ the trait of being active; moving or acting rapidly and 	<ul style="list-style-type: none"> ▶ any piece of work that is undertaken or attempted (www.cogsci.princeton.edu/cgi-bin/webwn) ▶ a specific piece of work required to be done as a duty or for a specific fee (www.cogsci.princeton.edu/cgi-bin/webwn) ▶ A sequence of user actions with a definite beginning and an end. (www.asrl.com/assist/glossary.h)

Occupation	Activity	Task
<ul style="list-style-type: none"> ▶ A group of jobs having common or closely related responsibilities and duties, and occurring in representative industries throughout the country (www.ntatt.org/glossary.html). ▶ A group of similar jobs found in different industries or organisations (workinfontet.bc.ca/lmisi/making/append/appendb.htm) ▶ The name of a job that identifies a person's principle business or work activity (jobs.utah.gov/wi/glossaryofterms.asp) ▶ a category of jobs that involve similar activities at different work sites (www.nelson.com/nelson/sociology/sociologyinourtimes2/glossary4.html) 	<p>energetically (www.cogsci.princeton.edu/cgi-bin/webwn)</p> <ul style="list-style-type: none"> ▶ A named process, function, or task that occurs over time and has recognisable results (www.ichnet.org/glossary.htm) ▶ Actions taken or work performed in a project to produce specific outputs by using inputs, such as funds, technical assistance and other types of resources. (www.ifad.org/evaluation/guide/annexa/a.htm) ▶ An element of work performed during the course of a project. (www.cs.mdx.ac.uk/research/SFC/Glossary.htm) ▶ Portion of the rest-activity cycle that is spent out of bed (www.unizh.ch/phar/sleep/glossary.htm) 	<p>tm)</p> <ul style="list-style-type: none"> ▶ the goals or a desired end-result of activities a user wants to achieve. (www.ucc.ie/hfrg/baseline/glossary.html) ▶ A task is a set of physical and cognitive procedures that when combined serve to achieve a particular goal (www.thf-inc.com/glossary.htm) ▶ A specific, definable activity to perform an assigned piece of work, often finished within a certain time (www.asq.org/info/glossary/t.html) ▶ A single instance of a real-time computation that must complete by a certain time (www.cs.utah.edu/~regehr/papers/diss/doc-wwwap1.html) ▶ A finite sequence of user activities or system functions(www.is4all.ics.forth.gr/html/definitions.html)

Note. The online addresses provide specific dictionary and glossary source information. The table illustrates the range of semantic understanding involved, variation stemming from domain interpretation versus everyday or common usage.

As can be seen occupation is commonly understood as primarily referring to chief productive role or paid occupation but activities are generally of a lower order referring to the execution of a lower level task or action (Nelson, & Jepson-Thomas, 2003). While activities and tasks at times appear to be synonymous, tasks are more typically thought of as lower level and discrete steps undertaken in activity completion. Ability and skill also appear at times synonymous, however skill implies either a natural or acquired facility in a specific activity. Skills are thus innate, acquired or lost over a life span.

Cooper, Cohen, & Risteen-Hasselkus (1991) suggested an activity-based conceptual framework as a good starting point for thinking about more supportive environments for people with disabilities. They articulated the following ten activity-based concepts as being central to any activity related vision.

1. Passing through openings
2. Operating electronic and mechanical controls
3. Moving along route of travel
4. Negotiating changes in level
5. Transferring from one body posture to another
6. Searching for and interpreting direction finding information

-
7. Negotiating a series of movements in a confined space
 8. Negotiating human and vehicular traffic
 9. Using fixtures, storage, and work surfaces
 10. Avoiding hazards in the path of access

While activity and environmental interaction are implicit in their conceptualisation of activity, there are problems with this approach. For instance, while behavioural actions are clearly related to specific environmental attributes like openings, pathways etc., this is implicit not explicit. Also, the list appears overly general and the level of decomposition appears uneven. That is, most of the listed activities can be further decomposed into tasks and it is unclear how this might be standardised. In this case, the activity of passing through a hinged door with a latch in a wheelchair typically has at least four tasks associated. First the door must be approached; second the locking mechanism must be released. Third there is passing through and finally the door is closed to prevent injury to others or obstruction to the adjacent space prior to moving on.

However the associated spatial envelope required to perform these tasks efficiently and safely varies depending on the type of approach, the type of door, actual clear door width not to mention the variables associated with the make and model of the wheelchair and the actual human particulars such as degree and type of impairment and corresponding ability. Additionally, the use of activity categories such as ‘negotiating a series of manoeuvres in a confined space’ are not clearly associated with either a particular purpose or a particular spatial arrangement so are difficult to operationalise. Presumably they refer to the movements made by a person with limited mobility such as a wheelchair user to in order to approach a door, operate a control, reach an object etc. In order to carry out this type of activity under less than optimal spatial arrangements adaptation of the activity by the user typically occurs such as introducing three-point and ‘U’ turns.

Nevertheless activities can be seen as particular behavioural actions that occupy a particular environmental setting (Kielhofner, 2002). This is important because inherent in this distinction remains the notion of activities taking place in particular environmental spaces. The connection between human activities and environmental spaces are readily recognised and the built environment is generally thought of as having designated activity purpose (Rowles, 1991).

The first attempt to articulate human abilities in conjunction with the environment resulted in the Enabler ideogram illustrated in Figure 5.8. The Enabler ideogram was developed by Steinfeld et al. (1979) as the basis for representing functional limitations that impact on person-environment fit. The key concept being that certain design attributes had a particular

functional impact on human responses. For example, door width as an environmental attribute of a designed object becomes critical for someone whose girth or assistive device use requires wider than average circulation space but may not be critical for someone with hearing or visual loss.

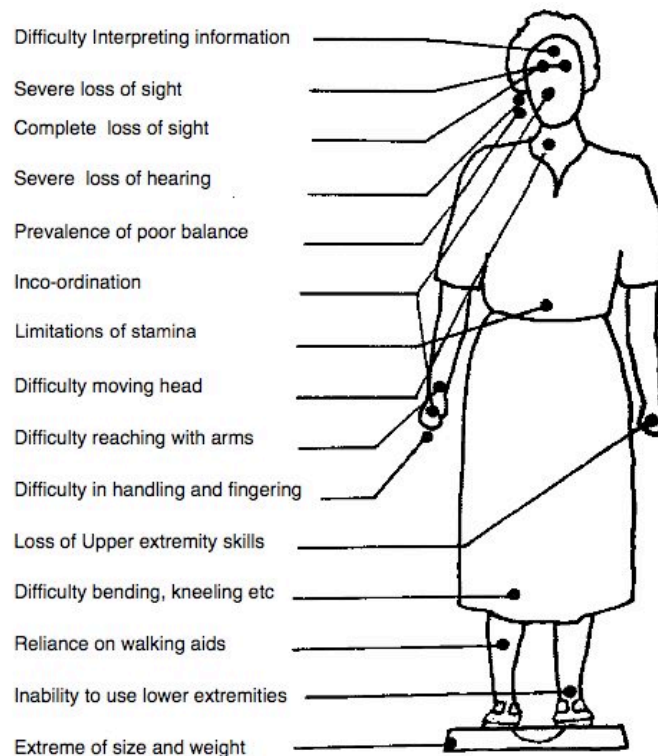


Figure 5.8: Enabler ideogram (adapted from Kidd & Clark, 1988, p. 40)

The original Enabler ideogram, as published by Steinfeld et al. (1979), appeared male and listed fifteen functional or human impairment categories these are as follows in Table 5.8.

Table 5.8: Human functional response categories of relevance to interaction with the physical environment

Category	Description
Difficulty in interpreting information	Impaired ability to read or reason and/or limited ability to interpret complex information.
Severe loss of sight	Impaired ability to read ordinary newspaper print with eyeglasses, legal blindness (20/200), or vision field defect of 10% or less.
Complete loss of sight	Loss of edge contrast and colour or vision field defect of 11% or more
Severe loss of hearing	Impaired ability to understand human speech with or without amplification.
Prevalence of poor balance	Impaired ability to monitor position in space and dynamically correct for changes in centre of gravity.
Incoordination	Impaired ability to place, control or direct extremities.
Limitations of stamina	Impaired ability to sustain adequate oxygen and blood pressure levels while carrying out tasks.
Difficulty moving head	Impaired ability to scan full visual field without reposition entire body.
Difficulty in lifting and	Impaired range of motion and/or muscle strength in upper limbs.

Category	Description
reaching with arms	
Difficulty in handling or fingering	Impaired ability to pickup, hold, place and manipulate objects.
Inability to perform upper extremity skills	Complete paralysis or absence of upper extremities.
Difficulty in bending, turning, sitting or kneeling	Impaired ability to flex and extend spine, pelvis and/or hip, knee joints.
Reliance on walking aids	Impaired ability to ambulate requires assistive devices (crutches, canes, frames etc.).
Inability to use lower extremities	Complete paralysis or absence of lower limbs requires assistive devices (wheelchair, scooter board or electric scooter etc.)
Extremes of size and weight	Human measurement (Anthropometric) extremes for height and weight.

The enabler framework provided the basis for the development of problem identification matrices. The transactional nature of activities is implicit within the matrix structure. The fifteen problem identification matrices in the original version covered attributes of outdoor circulation paths, parking, curb ramps, landscape furniture, entrances, interior circulation paths, vertical circulation, storage and work surfaces, space clearances, supports, controls, plumbing and communications. The impairment attributes were selected based on evidence of environmental interaction based on literature review and consultation with experts. The intent of matrix development was to assist designers to better comprehend potential environmental barriers to human participation and engagement with artefacts and to underscore the range of human abilities that require consideration.

In the enabler the *activity of passing through* an environmental attribute such as a doorway by a person with extremes of girth signals that a problem may be likely in a particular design manifestation. Thus the enabler assists a designer, to sense or anticipate, potential design problems. However, it is the actual experience of being unable to pass through an existing doorway that signals redesign will be required. What is of interest in relation to this thesis is that it is *activities* that provides the implicit transactional connection between attributes of the environment and attributes of the human impairment limitation. It is for this reason that Iwarsson & Slaug (2001) chose to use a much-expanded enabler as the conceptual basis for the development of the housing Enabler assessment tool.

5.5.1 Limitations of existing frameworks for describing activity transactions

Unfortunately, neither the ICF or the enabler frameworks as originally conceptualised take into account the habits or the preferred activity forms belonging to a particular individual nor do they adequately encompass the fact that activities are performed by human individuals in environmental settings using equipment or activity performance aids. Habits influence a wide range of behaviour and thus enable activity effectiveness within particular environmental

settings (Kielhofner, 1995). Habits are dependent on familiar environmental and/or activity contexts for their execution and as Camic (1986) laments, are typically forgotten or overlooked in most analyses of human activity performance. According to Kielhofner (2002), habits play a particularly important role for people with disabilities particularly in terms of cognitive load and variability in performance.

Many activities performed by humans require equipment and assume particular device use. For instance the activity of grooming requires manipulation of toothbrushes, hairbrushes and razors to aid performance. However, people with disabilities often require equipment to compensate for performance limitations. This may be modification to commercially available tools such as when a tool handle is enlarged or built up to compensate for weak grasp, but more commonly encompasses hand-held showers, wheelchairs and mechanical lifters which, while they may be used by persons without activity impairments, are commonly only provided to compensate for disability limitations.

For this reason, aids and equipment used by people with disabilities are generally defined as “products that assist a person with a disability by improving their functioning, increasing participation in society and/or improving their quality of life” (Australian Institute of Health and Welfare, 2003, p. 4). Part of the definitional separation relates to the fact that the majority of cost free equipment provision of essential aids and equipment for people with disabilities relies on eligibility determination. Like environmental support, the use of equipment by disabled persons more effectively reduces disability limitation than other types of assistance (Verbrugge, Rennert, & Madans, 1997). In Australia, nearly half of all people with disabilities report aid and equipment usage (48%); usage is greatest for older persons with 65% of persons with disability over the age of 65 reporting usage (Australian Institute of Health and Welfare, 2003).

5.5.2 Advantages of an enhanced enabling ability framework

As has been previously mentioned, at some point during the lifespan nearly everybody will experience some form of temporary or permanent human impairment and whether they are handicapped or excluded by this, often depends on the extent to which the built environment enables or disables users. Moreover, a social model of disablement sees ‘architectural disability’ as an encounter with a contextually relevant building object that prevents a user performing an *activity* required for participation, whether or not they have the label of person with a disability (Goldsmith. 1997).

Architectural disablement can thus be said to exist even when no medical or health related condition is apparent. For instance, when undertaking particular activities such as pushing a

shopping trolley or a baby pram or when moving large items of furniture the lack of a ramp or the width of a doorway can just as easily inconvenience or prevent entry despite so called 'normal' human anthropometrics and ability (Goldsmith, 1997). Thus, an activity based redesign model will benefit all human centred redesign not just redesign for people with disabilities.

A framework for associating personal attributes and environmental attributes is illustrated in Figure 5.9, this illustration places *activity* at its centre and uses *activity* to capture the transactional dynamism between people and their environments. It views individuals as having body function and anthropometrics in conjunction with socially acquired skill and knowledge. An individuals ability to perform activities is shaped, on the one hand, by their health status and activity forms or preferred performance habit/routines while on the other hand, by the environmental setting shapes activities by application of building conventions that define activity spaces and the equipment availability, type and quality required for optimal activity performance.

Based on the ICF framework, the new activity centric model takes as its starting point Lewin's idea of behaviour and transmutes this to the observed qualities of activity performance. Observations of activity or task performance are the norm for measuring accessibility and usability and are generally attributed a high level of face validity (Steinfeld & Danford, 1999). However, Steinfeld and Danford go on to argue that physical observations alone fails to account for the complexity of factors influencing performance especially those associated with individual interpretations and social expectations which is why Lewin's more simplistic conceptualisation ultimately fails to satisfy.

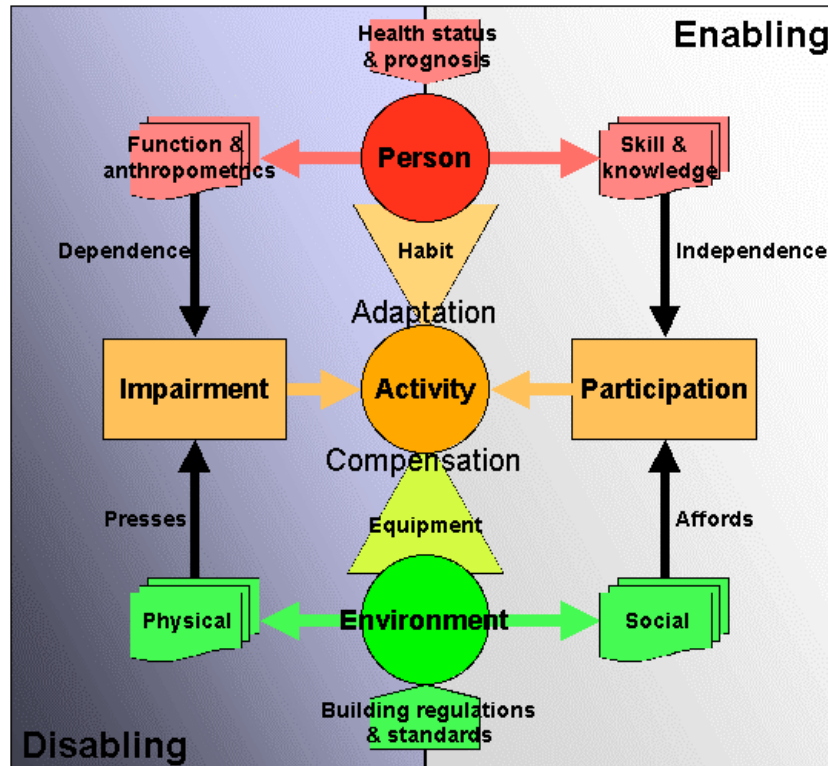


Figure 5.9: Activity centric dynamic between the person and the environment

The goals of social inclusion, equal rights and equal opportunities are all inherent in performance of activities like entering, passing through, listening, viewing, applauding, etc. However it is the interaction between individuals and their environmental setting that enables the development, practice and fulfilment of personally valued activities (Schkade, & McClung, 2001). Thus the concept of human *ability*, as developed in this thesis and based on the activity centric person-environmental dynamic, can be defined as being the quality of activity performance (A), which results from impairment (negative activity performance (I) over participation (positive activity performance) (P), times human individual (H) over environment setting (E) factors. Equation 2 symbolically expresses this as a dynamic transaction between activity enablers and disablers.

$$Ability = A \left(\frac{I}{P} \times \frac{H}{E} \right)$$

Equation 2: Symbolic formulation of the human ability concept.

The significance of this conceptualisation lies in the formalisation of relationships and in the provision of a mechanism for reasoning about redesign outcome in terms of the goal of enabling human ability. Because activity performance fluctuates over time and between environmental contexts, this conceptualisation captures context using time slices in the form of redesign reasoning instances for people with disabilities.

Thus, the inclusion of a framework for capturing and manipulating human factor data using *activities* as the lynchpin extends the redesign model as previously outlined in chapter four. Furthermore, a redesign model based on human ability requires a means of relating the person and the building using *activities* and this means extending the existing building product design models to include relevant building attributes, activities and human factor data. Therefore the standard building product entities as already discussed in the redesign model must be extended while preserving the structure and relations already outlined.

5.6 Reflexive Summary

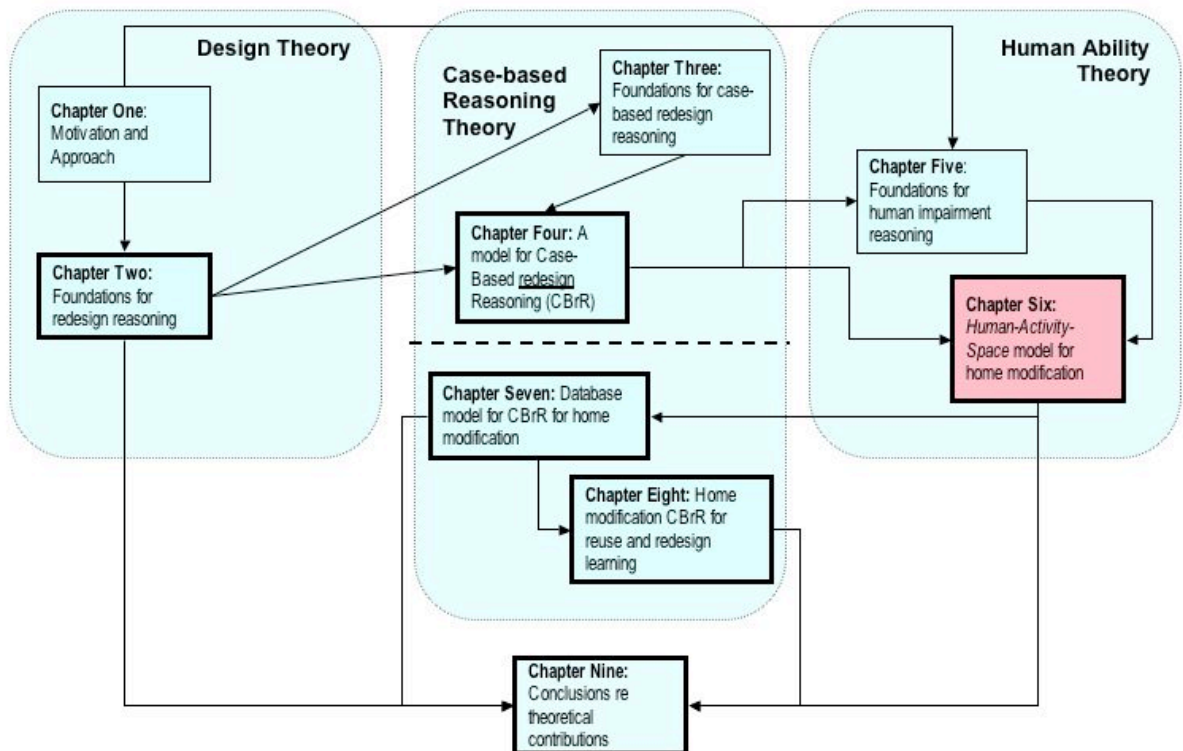
This chapter set out to explore *what aspects of humans with ability impairments (disability) is important for environmental redesign*, as any perspective on how a CBrR might function stems from an understanding of how computer applications can assist in capturing and better understanding human responses to the built environment. Understanding the theoretical, legislative and social underpinnings allows an appreciation of the salient issues associated with capturing knowledge needed to develop appropriate digital representations. Lack of existing methods for capturing the full variance in human ability limits generalisation of redesign principles and contributes to design that excludes.

This chapter has laid out the basis for understanding how assumptions about ability translate to design and suggests how consideration of human impairment translates to redesign. Specifically the contributions of this chapter facilitate norms for redesign case ontology structure as follows:

- ▶ The relations between environmental context and human functionality must be made explicit.
- ▶ Detailed articulation of all ICF components (e.g., particularly some of those relating to domains and categories at different levels of changes in body functions and structures) remains impractical for home modification practice because of their complexity, therefore a streamlined set of ICF components that adequately cover human body structures and functions, activities and home environments applicable home modification redesign applications needs to be made.
- ▶ The conceptual categories need to be inclusive of functional ability and activity variation rather than assume standardisation or uniformity.
- ▶ Understanding dynamic transactions requires a means of capturing pattern regularity. This requires data about the new redesign requirements, the existing object description, and the redesign description.

Understanding and encoding redesign requirements for all humans and people with disabilities in particular means encoding attributes of the human performer (i.e. their abilities and body specifics) and attributes of the activity (i.e. type and quality) in relation to the environmental setting. This preservation of context is critical in making judgments about success or otherwise of outcomes (Bridge, 1994). Gathering detailed data about human responses to designed artefacts underpins all informed decision making and assists formulation of more widely generalisable design principles.

6



Human-Activity-Space model for home modification

Chapter 6: Human-Activity-Space model for home modification

6.1 Introduction

This sets out to answer the question of: *what ontological model might best capture and relate human activity and spatial features?* Redesign reasoning in home modification requires a model for linking human activities and spatial environments. Therefore a conceptual ontology that extends the theoretical understandings of human impairment described in chapter five, must be extended to include terms and attributes relating to residential spaces. Using existing disability frameworks such as the ICF provides a domain relevant foundation but it fails to deal adequately with the spatial aspects of housing. Consequently, extending human ability understandings to better include relevant spatial concepts provides the basis for computational formalisms relevant to storing, recalling, and reusing home modification cases for people with disabilities.

Domain ontologies are constructed to address particular purposes and thus no universal form exists for constructing any particular domain ontology (Simoff & Maher, 1998a). The Human-Activity-Space model outlined in detail within this chapter defines the vocabulary employed and outlines the constraints on how terms are employed to model the redesign domain. The hierarchical structure presented has the advantage of being extensible, decomposable, modular and is highly relevant to the domain of concern. Terminological relevancy is critical for interoperability and understandability (Stone, 2003). The need to organise the redesign case knowledge to facilitate case acquisition and case storage drives ontological development and understanding. The resulting intermediate representation provides a foundation for the more formal representational ontology presented in chapter seven.

6.2 Chapter structure

This chapter is structured into several parts to assist an understanding of the redesign housing model being developed, its constructs, relations, advantages and limitations. First, existing models such as the *Activity-Space* model (Maher, Simoff & Mitchell, 1997; Simoff & Maher, 1998a) for building design is overviewed. This model focuses on architectural design and encompasses both virtual and bounded spaces as its primary knowledge framework. The advantages of an activity centric means of capturing human ability is then related to the human impairment redesign process.

Second, exploration of building design concerns relevant to human impairment redesign commences by introduction and review of the *Accessible-Building* model (Bridge & Simoff, 2000a, 2000b). This model provides an understanding of how domain constructs of environmental settings can be encoded and related to the redesign reasoning process. The *Accessible-Building* model demonstrates how environmentally relevant redesign case attributes can be classed and/organised.

Third, these existing models are combined and extended to form a new *Human-Activity-Space* ontology as a means of demonstrating how human and building domain knowledge attributes can be grouped and ordered in a computational system. Finally the implications of the *Human-Activity-Space* model for CBrR are outlined in order to demonstrate the suitability of this modelling approach for the purpose of integrating human ability and environmental redesign knowledge representation into a CBR system.

6.3 Activity-Space model

Clearly space is critical in person-environment transactions. For instance, according to Velde and Fidler (2002), a relationship between space and activity reflects the value and priority pertaining to that activity. A model that serves to formalise these two elements is the *Activity-Space* model (Maher, Simoff, & Mitchell, 1997; Simoff & Maher, 1998a). It differs from other representational formalisms for building design knowledge that focus on the structure and function of components but neglect the primary but implicit purpose, which is creation of an environment for human activity. Building design models have building centric features and activity descriptions can only be incorporated if an existing spatial description extension included a specific activity function. For instance, a bathroom could have a feature description included such as allow ablution activity. Nevertheless, this assumes that all similar spatial descriptions can be generalised to include the same sets of activities. Moreover, part of the aim of developing the *Activity-Space* model included overcoming the hard coding of activities within spatial descriptions. The *Activity-Space* model instead, defines spaces and activities as separate entities but links them into the total building design descriptions (see Figure 6.1).

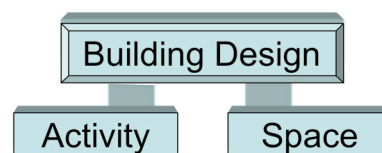


Figure 6.1: Activity-Space design ontology (Simoff & Maher, 1998a, p. 27)

In articulating activities, the model builds on the notion of ergonomic fit, which separates spaces into activity zones (De Chiara & Callender, 1990). In the model, *activity* is defined as “a purposeful action whose performance requires a particular amount of space, time and an object that performs this activity” and *space* is a “coalescence of all activity components, necessary to perform that activity” (Simoff & Maher, 1998a, p. 27).

As can be seen in Figure 6.2, activity has the ontological elements of equipment, service, time, performer, consumer and constraints. However, space has the ontological elements of geometry, divider, link and constraints. As well as holding conceptual knowledge, this model holds relationship knowledge that is used to describe the connection between entities.

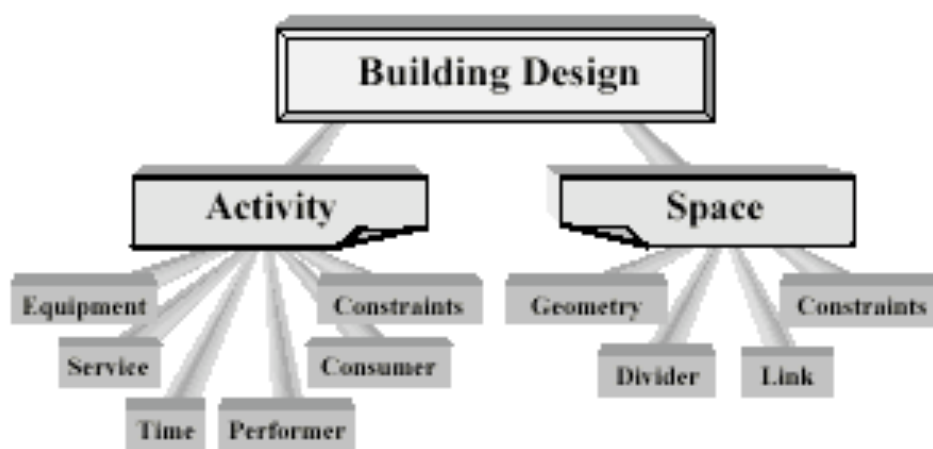


Figure 6.2: The Activity-Space architectural building design ontology (Simoff & Maher, 1998c, p. 5)

The *Activity-Space* Model was originally developed in the late 90s with the primary purpose being to better represent the spatial and activity information related to building design that prior research had previously overlooked (Maher et al., 1997; Simoff & Maher, 1998a, 1998b, 1998c). The model built from earlier work on space describing languages begun in the 1970’s. The Activity-Space design ontology facilitates the explicit computational representation of the categories of knowledge needed to describe spaces, activities and their relationships. Benefits flowing from the application of data formalisation using the model are specific to architectural designs where spaces or voids are as important as the solid objects more typically modelled. The Activity-Space model provides formalised knowledge blocks, which are computationally useful for describing and linking building design, requirements, components and relations.

Additionally, the standardisation and improved regularity of design documentation afforded by the Activity-Space ontology resulted in improvements in performance measurement especially from the facilities management perspective (Maher et al., 1997; Simoff & Maher,

1998a). Nevertheless the model fails like all existing building design models to adequately articulate the full range of human ability which acts to exclude those whose abilities fall outside those of the adult healthy male (Imrie & Wells, 1993; Liebig & Sheets, 1998; Van de Voordt, 1999). In redesign the ability to capture and formalise human ability knowledge is vital. Building redesign for persons with disabilities typically occurs because building construction fails to allow for variation in spatial requirement of persons with disabilities (Iwarsson & Isacsson, 1993; Levine & Gitlin, 1990; Littrell, 1989).

For this reason, human, activity and space variables must be made explicit ontologically and transactionally. The *Activity-Space* design ontology provides a foundation for extension to include human ability and human impairment. The *Human-Activity-Space* extension attempts to address the under representation of human knowledge within the building domain, particularly knowledge relevant to problem framing in redesign for people with disabilities. For instance, in terms of access to buildings and facilities, it is a question of degree depending on design assumptions about user ability. Examination of the steepness of a gradient, the available circulation space at a doorway, the type, fixation and position of a handrail, the amount of colour contrast and lack of other sensory cues determines the range and magnitude of the human abilities required. Human ability determines the success or otherwise of activity engagement. These same activities constitute the habits and routines of daily life. Last but not least, the *Activity-Space* model meets the need to integrate building spaces within a model of human activity requirements. Moreover, articulation of human impairment requirements as performer and ability sets thus becomes possible.

6.4 Accessible-Building model

All existing data models for design including building and facility design fail to capture and manage human impairment domain concepts such as those embodied in access requirements. For instance, an abstract concept incorporated into access requirements concerns the operationalisation of abstract and difficult to specify notions such as ‘a continuous accessible path of travel’ (Standards Australia, 2001). Ascertaining a continuous path of travel for instance requires that all routes joining facilities, building and spaces can be identified to determine if they are or are not accessible and if accessible are continuous. If any part of the route is inaccessible the route itself becomes inaccessible, meaning that a human with an impairment of mobility would be unable to access the facility, building, or space regardless of whether or not the facility, building or space were accessible or not.

Thus, determination of accessibility of a route requires explicit representation of accessible building entities. The *Accessible-Building* model used in this thesis is based on the idea of representation of all characteristics of building design relevant to person-environment fit. For

example, the operationalisation of ‘a continuous accessible path of travel’ can be achieved only when all the activities required for access and egress can be accomplished without architectural barriers or impediments. In this case, this requires the division of routes from that of spaces. The accessibility of a route cannot be computed as required unless these space and route entities can be distinguished (e.g., a route leads to a space not within the whole space itself). In this manner a building is a collection of spaces and links whilst links compromise routes that connect buildings. Links are thus more likely to comprise virtual areas i.e. may not have walls and ceilings. For instance, a student in a wheelchair might need to attend a lecture. For that to occur all the links comprising the route from the person’s home to the lecture space must be accessible. However not all aspects of the lecture space must be accessible for the person to carry out their required activities (i.e. taking notes does not require access to the lecture podium).

Concurrent work on the development of a computerised database for access auditing, leads to the development of the *Accessible-Building* model. The skeleton for the *Accessible-Building* model is based on knowledge representation work described in (Bridge & Simoff, 2000a, 2000b). Four critical groups of accessible entities were identified whose common construct characteristics could be grouped into common entity sets. Thus the conceptual model underpinning auditing and design of buildings for access by persons with disabilities stems from the identification of entities whose common characteristics were united in four basic constructs named as ‘Space’, ‘Link’ ‘Access Point’ and ‘Service’. The construct definitions for the Accessible-Building model are outlined in Table 6.1 as described in Bridge and Simoff (2000a, 2000b).

Table 6.1: Accessible-Building construct definitions

Term	Definition
Space	a three-dimensional hypothetically or physically bounded space that enables one or more required activities. This definition accommodates both closed and open spaces, for example, the same common modelling attributes can be defined for a room and a car park space. Space entities accommodate variety of activities related to the human ability. Living room, bedroom, office room, toilet, car park are example of spaces.
Link	a three-dimensional hypothetically or physically bounded space, which only function in the model is to provide a travel path from one space to another. Corridor, stairway, vehicular crossing are examples of links.
Access Point	an entity whose function is to connect and/or provide access between spaces and links. Doorway, hinged door, and gate are example of typical access points. Access points can connect: <ul style="list-style-type: none"> ▶ two spaces, for example, a door between two rooms; ▶ a space and a link, for example, a door between a room and a corridor; ▶ two links, for example, a change in level between two corridors.
Services	an entity that accommodates a variety of devices that are used to provide

necessary services for supporting desired activities. Rubbish bin, washing line, oven, vanity, table, telephone, letterbox are examples of services.

Note. Some residential spaces may also serve to connect i.e. a foyer or family room. However in this model a space is defined by its primary activity functions not its connection functions. Links are in this sense only used when they have a singular function i.e. only serve to join spaces i.e. home to shed.

The work undertaken to develop this model involved interdisciplinary knowledge collaboration (Bridge & Simoff, 2000b), as shown in Figure 6.3. Information from the domain of occupational therapy, facilities management and building design/redesign were integrated. The model makes possible conceptual interpretation of space performance in regard to human impairment.

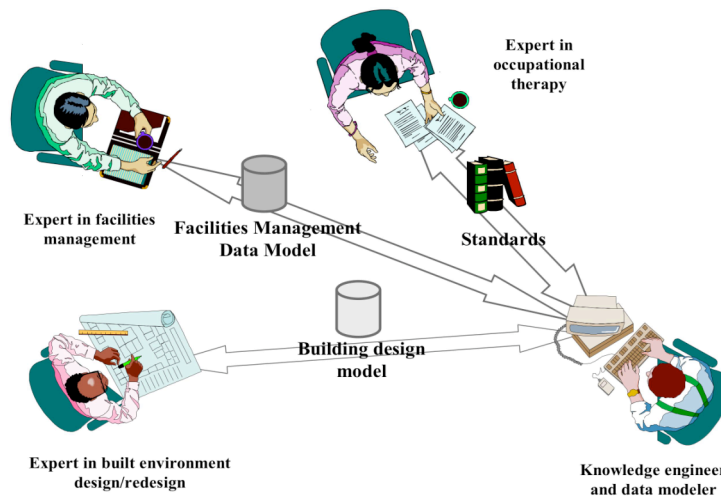


Figure 6.3: Basic participants in the information modelling stage of the Accessible-Building model (Bridge & Simoff, 2000b, p. 245)

A more formal graph representation of the conceptual model as originally developed and published is illustrated in Figure 6.4.

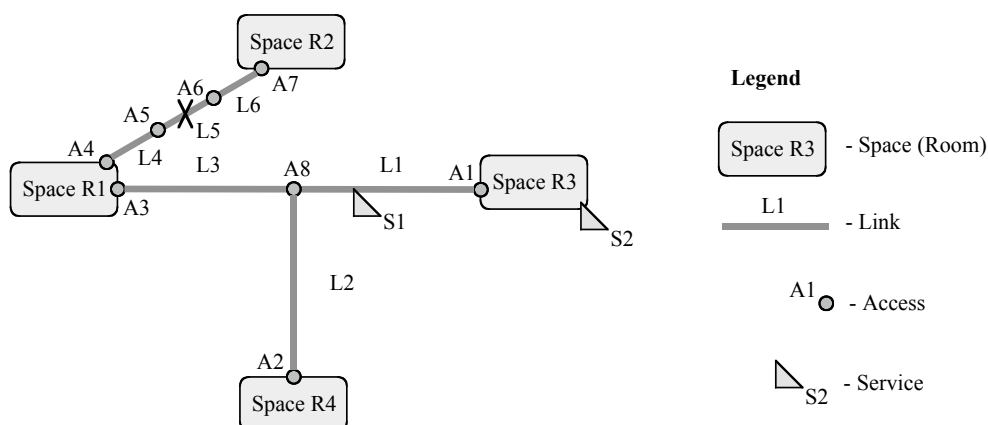


Figure 6.4: Illustration of conceptual basis of the 'Accessible-Building' model (Bridge & Simoff, 2000b, p. 247)

The whole point of the *Accessible-Building* data model stems from the need to capture accessibility of a particular space with respect to other adjoining spaces. In this manner, a space becomes accessible to a particular person with a disability if every link and access in the ‘accessible route’, i.e. the linked set of spaces, access points and links needing to be traversed, meets the necessary requirements for a particular form of access. For example, space R1 is accessible from space R3 as far as links L1 and L3 satisfy all criteria for human impairment access. Room R2 cannot be accessed from room R1 because link L5 does not satisfy at least one criterion. Depending on the accessibility criteria, we can have a case of *partial accessibility*, depending on the manner in which we define *structural* and *disability access* relations between these entities. Structural relations represent the physical structure when disability access relations are connected with the disability access criteria. The entity-relationship (E-R) diagram in Figure 6.5 shows the basic structural relationships employed in this conceptual model.

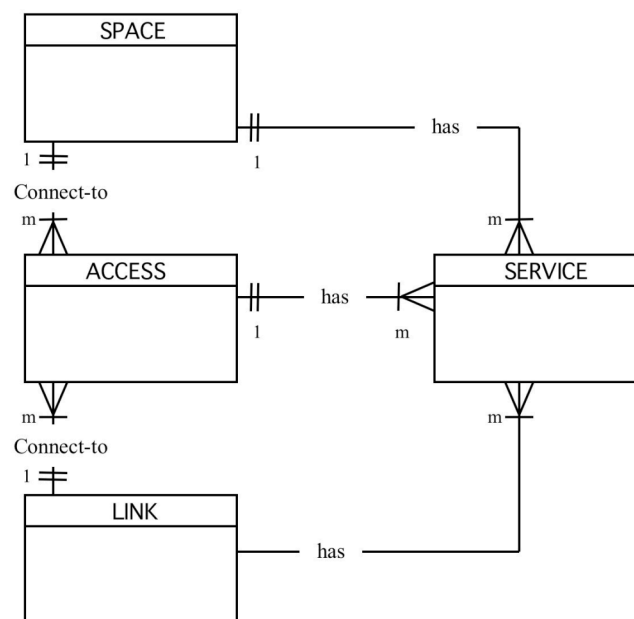


Figure 6.5: Basic structural relations in the ‘Accessible-Building’ model (Bridge & Simoff, 2000b, p. 247)

The entity sets labelled ‘Space’, ‘Link’ and ‘Access Point’ can have one or more services attached to it. In addition, the entity set labelled ‘Space’ may have many access points connected to it. Each ‘Link’, can also have multiple access points. Our *Accessible-Building* taxonomy allows the representation of any building or facility and their parts can be represented as a combination of these four basic entities. A level in a building is a collection of spaces and links with associated access points and services. Thus a building is a collection of levels and internal links, i.e. a collection of spaces, links and access points forms a

building. Car parking spaces are represented as individual spaces, the road along them as a link or collection of links, and the entrance to each space as an access point. Representation in this way thus leads to a model similar to the model of a level within a building.

The *Accessible-Building* model is based on object-oriented descriptions, a door is described as an access point and elements are organised into structural and functional values (i.e. Door-structure has attributes of material, type, opening, fixings, width and connections with associated symbolic values). This modification and integration of existing models appears to capture well salient aspects needed for both conceptual (problem assessment) and actual redesign (building fabric modification) for persons with disabilities. However it still fails to capture the disabled persons attributes which determine the new or additional redesign requirements.

6.5 Human-Activity-Space model

In this section, an extension of the existing Activity-Space and Accessible-Building models is presented as a means of bringing together the human person attributes in conjunction with the building environment attributes. For the theoretical reasons outlined in chapter five, the model developed has also to be *activity centric* as it is the performance of activities that invokes the human person's transaction dynamically within a particular environmental setting at a particular point in time. The Human-Activity-Space extension specifically addresses the redesign of building spaces in which the human abilities determine the spatial requirements, in contrast to the design of a building where dimensional minima believed to accommodate an average wheelchair user are specified and it is thought that compliance with these will enable inclusion i.e. almost one size fits all (Standards Australia, 1993, 2001).

The *Human-Activity-Space* model extension addresses the need to represent requirements corresponding to the individual activity limitations and abilities of all human users in relation to the activities desired to be performed within the spatial bounds presented by the building's geometry or physical descriptions. Like the original Activity-Space ontology, all the components of the extension are represented in a hierarchical ontological form that categorises and identifies the relevant knowledge.

The *Human-Activity-Space* ontology makes explicit the representation of human ability and the spatial or environmental bounds impacting on activity performance. For example, a client functional performance component, such as a health condition, and/or impairment of activity can be encoded as an attribute value pair (i.e. impairment has attributes relating to seeing, reaching, transferring etc. with corresponding values such as mild, moderate etc.). The relationship between individuals with multiple impairments, and the activity of toothbrushing

is illustrated in Figure 6.6. In the illustration, the building components include services (i.e. basin, mirror, faucets etc.) not spaces per se as activities occur within a space and the example given of toothbrushing typically occurs in a bathroom space.

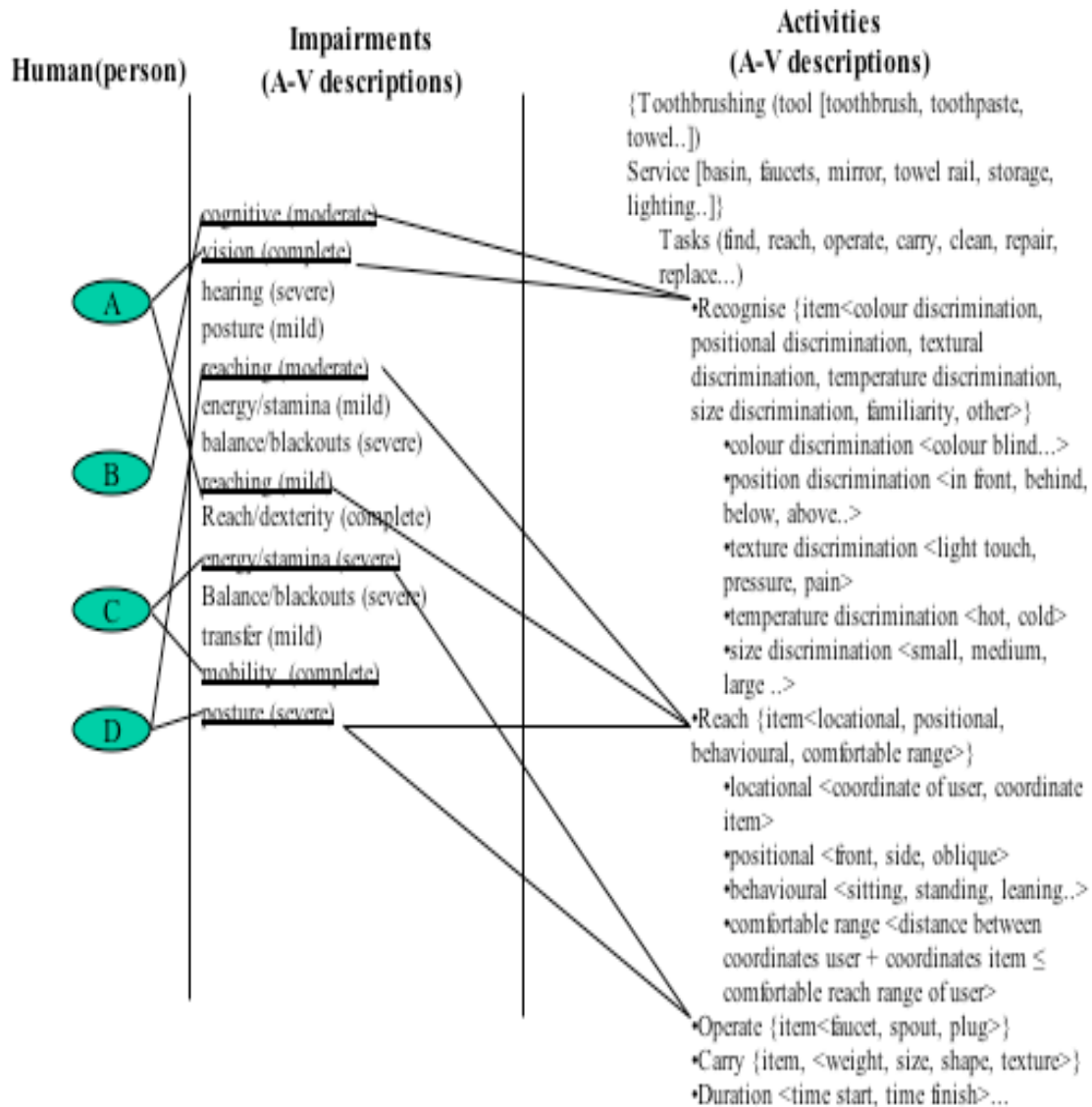


Figure 6.6: Indication of various human performers impairment and activity attributes can be captured within cases using the Human-Activity-Space ontology.

The purpose of the extension is threefold. First, as an improvement on the informational models already developed. Second, it provides a means of integrating human abilities and environmental attributes. Third, it enables a means of articulating the domain knowledge used by occupational therapists who are the functional performance and activity experts (Abraham, Boyle, Clamp, & Robson, 1987; Cooper et al., 1999, 2002; Law, Baum, & Dunn, 2001).

For the domain of building redesign, as illustrated in Figure 6.7, three primary construct categories are delineated. The concept of *human* builds from the theoretical and

terminological work regarding theoretical understandings of disability within the ICF, activity as in the Activity-Space ontology differs from traditional construction planning, and *modelling* which views *activity* in terms of the functionality of the design and like the ICF instead *activity* is viewed as behaviour performed by people within a particular environmental setting. However, unlike the ICF where *activity* is just a sub category of person in this models conceptualisation it provides the means of connecting human performance to environmental settings explicitly.

This knowledge model addresses the need to make explicit the representation of humans, activities and spaces. It specifically focuses on architectural or building redesign for people with disabilities in contrast to other forms of human impairment design such as design of accessible websites, disability equipment or accessible transport infrastructure where the focus on activities and spaces will be significantly different. The basic building blocks of the Human-Activity-Space ontological model developed in this thesis are illustrated in Figure 6.7.

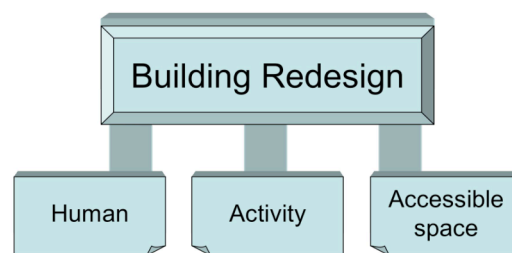


Figure 6.7: Human-Activity-Space ontology

Each of the three foundation constructs is represented in the form of a hierarchical ontology that more precisely captures the knowledge that specifies a human performer, their activities and the environmental space that the activities are performed in. The construct definitions for the Human-Activity-Space model are outlined in Table 6.2.

Table 6.2: Human-Activity-Space terminological construct definitions

Term	Definition
Human	The personal social and financial resources and attributes pertaining to a human individual that enable performance and participation in one or more required activities. This definition encompassed anthropometrics including height, weight and body structures components. It also encompasses abilities, impairments and health conditions.
Activity	The nature or extent of functioning at the level of a person. Activities may be limited in nature, duration or quality.
Space	A three-dimensional hypothetically or physically bounded space that enables one or more required activities. This definition accommodates both closed and open spaces, for example, the same common modelling attributes can be defined for a bedroom and a car parking space. Space entities accommodate a variety of activities related to activities of daily living. Bathroom, garage, patio are all examples of typical residential spaces.

The Human-Activity-Space model just described, has a *Human* component that describes a particular set of structure, function, health and impairment attributes, which in turn determines an individual's ability to carry out a particular set of desired activities. *Activities* are really the redesign goal and are dependent on the environmental affordances available within a particular residential *Space*. From viewing Figure 6.8, it becomes clear that the three Human-Activity-Space descriptions are all interrelated and all are required to explain why a particular person has a particular level of ability within a particular spatial environment.

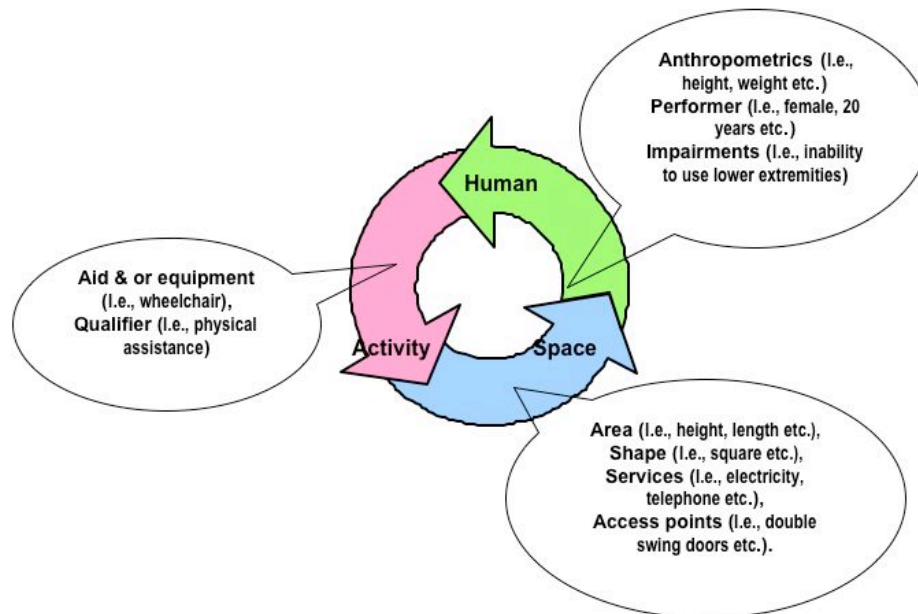


Figure 6.8: The Human-Activity-Space ontology showing interrelationship between components

6.6 Human ability, activity and spatial requirements in buildings

The practice of occupational therapy with persons with disabilities builds on the domain knowledge paradigm afforded by knowledge of the intersection of person, activity and environment (Iwarsson & Isacson, 1993; Law et al., 1994; Levine & Gitlin, 1990). In reality, most models within the profession of occupational therapy are predominantly person focused, as maximising the human abilities of persons with disability is the professional goal of intervention.

Human ability can be expressed as person related attributes concerning health status, body measurements or anthropometrics and skill. Thus human ability 'h' can be defined as a set of attributes belonging to a person and which, when called on as a part of activity performance, can be either enabled or impeded by the spatial environment in which the activity is being performed. The semantic structure of the human ontology is shown in Figure 6.9.

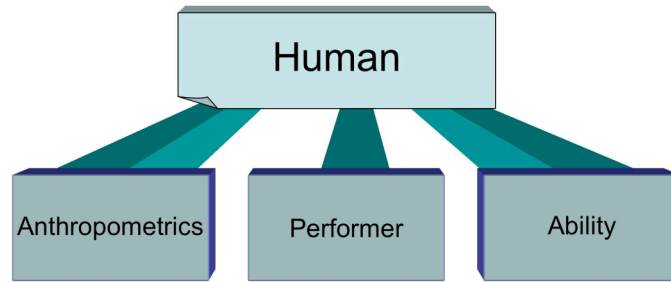


Figure 6.9: Human category and its ontological elements

The semantics of the model describing the three categories of human entities is laid out in Table 6.3 as follows. These are based on their common characteristics, which are grouped into three *basic* entity sets.

Table 6.3: Entity definitions in the human model

Term	Definition
Anthropometrics	A three-dimensional measure of human body dimensions and dynamics. This definition accommodates both static and dynamic measurements, for example, the same common modelling attributes include height, weight and limb segment Anthropometric entities accommodate a variety of body patterns such as bending and reaching which are required for independent activity performance.
Performer	A description of the set of unique characteristics of the human individual performing a particular activity. The performer entity’s function is to uniquely identify the individual involved in performing a particular activity. It enables multiple persons to perform activities within the same environmental setting, such as care provision.
Ability	A description of the functional abilities commonly possessed by human performers. Applying knowledge, seeing, hearing, balance, stamina, movement control, reaching, lifting, grasping, carrying, kicking, transferring are example of skills that are called on in activity performance. Skill levels enable or restrict activity performance: <ul style="list-style-type: none"> ▶ hearing, enables understanding and appropriate response to auditory stimuli, for example prompting an individual to respond to an incoming telephone call; ▶ absence of hearing, disables unless alternative environmental stimuli are present, for example vibration or flashing lights could also signify an incoming telephone call.

In the earlier Activity-Space model the notion of a performer was implicit but the quality of the performance was not considered and the performer element was only used to denote the object that carried out the activity. In the extension, the performer element provides the unique identifier that links all three aspects of a single case. Thus, the performer element remains the same while the other human elements are expanded to better capture the ability of the human performer. The full expansion of human entities is illustrated in Figure 6.10.

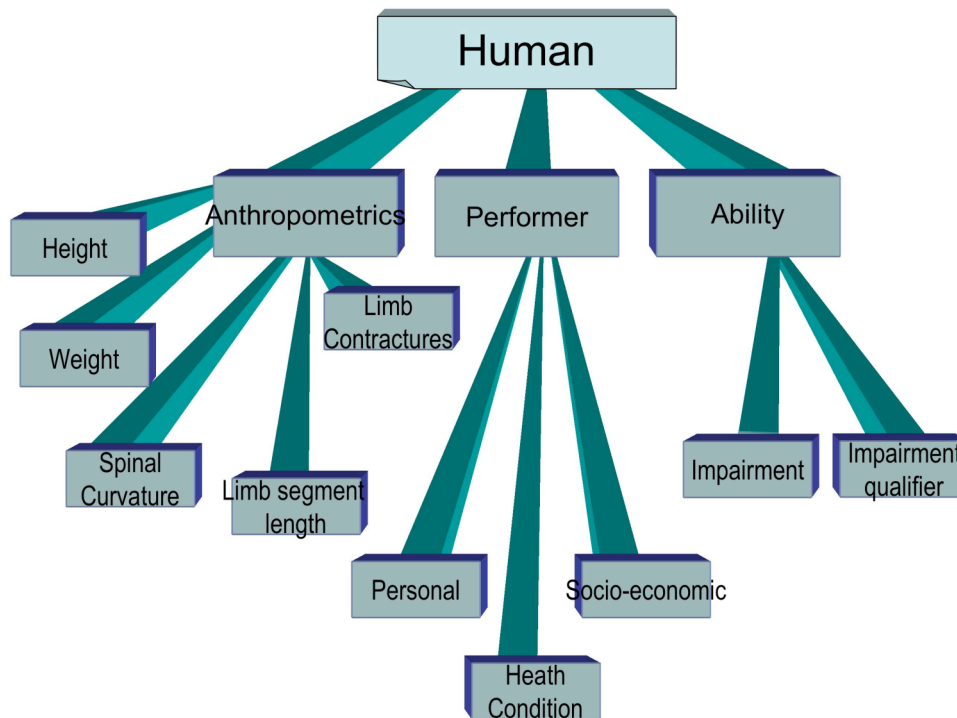


Figure 6.10: Human entities within the Human-Activity-Space ontology

The semantics of the human entities used within the Human-Activity-Space model are further classified into ten entity subcategory sets. Terminological descriptors are defined in Table 6.4 following.

Table 6.4: Human entity sub-category terminological descriptors

Term	Definition
Height	in the context of a human performers anthropometrics this represents ambulant and non-ambulant metric measurement of a human performer. The position of the top of the head activity performance and participation by determining reach, vision and hearing ranges. Examples: 760 mm, 1.305 mm etc.
Weight	in the context of a human performers anthropometrics this represents the metric totality of a particular performers body mass. This total weight of an individual determines structural safety during activity performance and participation. Examples: 50 kilos, 102 kilos etc.
Spinal curvature	in the context of a human performers anthropometrics these are spinal deformities impacting height and posture. The degree of deformity will determine the need for special equipment during activity performance and participation. Examples: scoliosis, kyphosis etc.
Limb segment length	in the context of a human performers anthropometrics these are the body structure deformities impacting activity performance and participation. Examples: in proportion, out of proportion etc.
Limb contractures	in the context of a human performers anthropometrics these are the body structure deformities impacting activity performance and participation.

Term	Definition
	Examples: absent, contracted etc.
Personal	in the context of a human performer these are the sexual, developmental and personal factors impacting activity performance and participation. Examples: female, eight years, animal lover etc.
Socio-economic	in the context of a human performer these are the social, financial and living arrangements pertaining to a particular individual in a particular environmental and time context Examples: care recipient, lives alone, pensioner etc.
Health Condition	in the context of a human performer these are the primary and secondary disease diagnostic and prognostic medical labels pertaining to a particular health condition. Examples: Parkinson's, Cerebral Vascular Accident, Macular degeneration etc.
Impairment	in the context of a human performer ability these are the functional descriptors resulting in a significant functional deviation or loss. Impairments are not contingent on health conditions or aetiology. Examples: vision, hearing, balance/blackouts (vestibular) etc..
Impairment qualifier	Are descriptors that classify impairments in the context of a particular environmental and time context. Once an impairment is noted, its impact can be rated using commonly accepted hierarchically graded severity indices. Examples: mild, moderate, severe, complete etc.

Most of the research on the relationship of the built environment to human activity performance has centred on abstracting data so that it can be encapsulated in building regulations, design norms, and standards but, as discussed in chapter five, the use of means and averages are minimums derived from incorrect assumptions, and these are often based on faulty and/or incomplete data sets for people with disabilities and so have worked to exclude those persons with disabilities at the widest ends of the range. Anthropometrics refers to the study of human body measurement for use in anthropological classification and comparison. Knowledge of individual human measurement permits the redesign of the environment to better accommodate the performers' abilities (Panero & Zelnik, 1979; Pheasant, 1986).

Moreover, adequate redesign practice for humans with ability limitations requires appropriate individual measurements (Goldsmith, 1984). An example of the how this type of individual measurement for individuals is typically collected and documented as a basis of redesign reasoning is illustrated in Figure 6.11.

Name: Elizabeth

Diagnosis: Spina Bifida

Age: 8 yrs

Height decreased by: spine [✓] comment: *marked scoliosis & lordosis*

(✓ if affected) lower limbs [✓] comment: *marked flexion contractures at knees & evidence of previous surgery to arthrodise ankles and stabilise hips, bilateral external hip rotation.*

✓ If no report	Reason for no report	Ambulant Person Standing (Diagram 21.1a)	Data (mm)
	Uses tummy prop	A. Comfortable vertical reach	1.540
✓	Cannot maintain static balance using crutches & reach simultaneously	B. Oblique vertical reach	
		C. Head height	1.280
		D. Eye level	1.150
		E. Shoulder level	1.010
		F. Elbow level	0.750
		G. Knuckle height (comfortable downward reach)	0.580
✓	Cannot maintain static balance using crutches & reach simultaneously	H. Effective downward reach	
✓	Cannot maintain static balance using crutches & reach simultaneously	J. Comfortable forward reach	
		K. Toe projection	0.160

Figure 6.11: Excerpt from typical anthropometric data collection form illustrating case data

The other critical knowledge element of the extended ontology is that of the activity. In the original Activity-Space model *activity* was defined “as a purposeful action, whose performance required a particular amount of space, time and an object to perform the action” (Simoff & Maher, 1998a, p27). Simoff and Maher go on to argue that the particular design context or design stage shapes other aspects. In redesign, *activity* provides the means to reason about person-environment fit. Thus it refers to a particular performers proficiency, facility, or dexterity that is acquired or developed through genetics, training and/or experience.

The primary redesign understanding of *activity* concerns capturing the functional ability of a particular performer within a particular environmental setting at a single period of time. Thus the elaboration of the terminological ontology focuses on functional descriptions and qualifiers pertaining to activity description. In building redesign, activity cannot be accurately modelled by consideration of the human performer alone. In the ICF framework, activity is a component of the person. However this more static representation fails to adequately capture

the transactional nature of person-environment interactions that can only be observed and measured in relation to activity outcomes. The full expansion of activity entities as conceived in the model extension in the domain of redesign is illustrated in Figure 6.12.

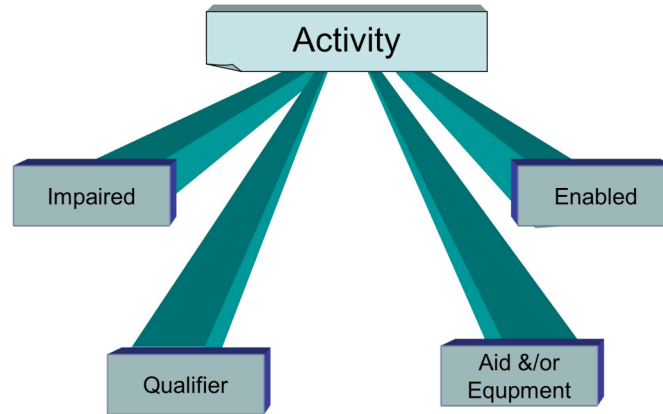


Figure 6.12: Activity entities within the Human-Activity-Space ontology

The semantics of these terminological categorisations is described with examples for operational clarification in Table 6.5.

Table 6.5: Activity entity descriptions

Term	Definition
Impaired	in the context of performing a particular activity the type of activity impaired limits a particular level of participation. Examples: bathing, dressing, cooking, shopping etc.
Qualifier	in the context of performing a particular activity the qualifier indicates the degree of assistance needed to perform and participate in a particular activity. Examples: independent, physical assistance, dependent etc
Aids &/or equipment	in the context of performing a particular activity the type of assistive equipment provided determines performance and participation in a particular activity. Examples: grabrail, shower chair, wheelchair etc
Enabled	in the context of performing a particular activity the type of activity enabled facilitates a particular level of participation. Examples: bathing, dressing, cooking, shopping etc

In this conceptualisation of activity performance, a human performer will be either enabled or impaired in performance of a particular activities within a particular environmental or spatial settings at a particular time. The entity descriptions provide some measure of quantification of aspects likely to impact quality of activity performance not accounted for outside a particular activity within a particular environmental setting. For instance, the activity of bathing in a tub will be impacted by the degree of assistance available. This assistance may be in the form of informal or formal care, both physical and directional, or in the form of objects designed to

supplement or extend human ability. For example a tub transfer device such as a hoist or bathboard.

6.7 Human-Activity-Space attributes and values as a conceptual basis for human ability

Following on from the construct and entity terminological definitions, it is now possible to discuss the relations that define the connections between entities for the extended Human-Activity-Space model. Ontological development requires that relevant hierarchical taxonomies and their relations be specified. In order to illustrate the handling of information using the model, as in the Accessible-Building model, a space becomes accessible to a person with disabilities only if each and every link and access point in the chain matches their disability requirements in relation to their ability and activity requirements.

For example in Figure 6.13, which illustrates a bubble diagram of the spatial related residential building entities for a particular home, the bathroom space is currently inaccessible from the bedroom space because:

- ▶ there are no direct access points; and
- ▶ because ‘Link 1’ represents stairs, which does not match the person with, disabilities ‘transferring abilities’ and so requires redesign to become more accessible.

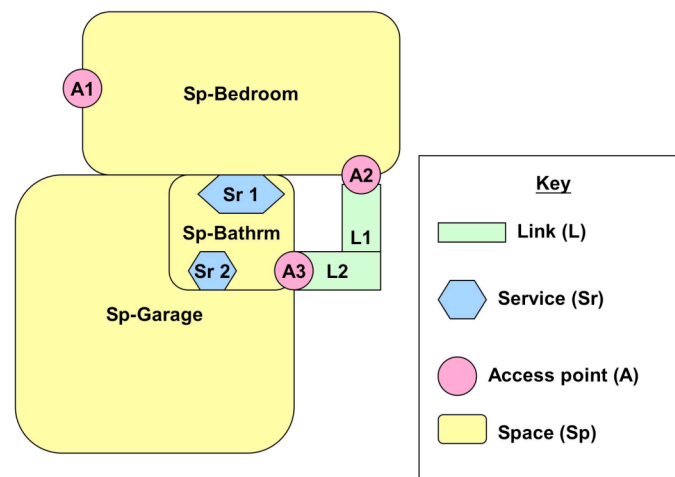


Figure 6.13: Bubble diagram of the Accessible-Building ontology

However the spatial elements alone only tell half the picture and fail to specify redesign requirements. The lack of access to the bathroom space only becomes a requirement for redesign when a human performer requires access to a particular space directly. The requirement for direct access stems from the fact that the current spatial arrangements exceed the human persons current performance capacity. Either the person cannot negotiate the stair ‘Link’ as a consequence of health condition limitations, or because their ability limitations

alter the activity performance itself in some manner. For instance the activity of toileting may become more frequent due to urinary tract infection or more hazardous if continued in its current form without increased lighting, ventilation or transfer support devices.

The conceptual model has been expressed in terms suitable for conversion to an object-relational schema, so it can be implemented in a computational or database system. In object-relational schema descriptions, database development requires that object relations are not just specified but that their relations and unique identifiers are also specified. In a database conceptual schema ‘n’ denotes the size of the group that it models. In other words, it has a table with all the common attributes and ‘n’ tables with the specific attributes for each different entity type. The idea is illustrated in Figure 6.14, which is an Entity-Relationship (E-R) diagram.

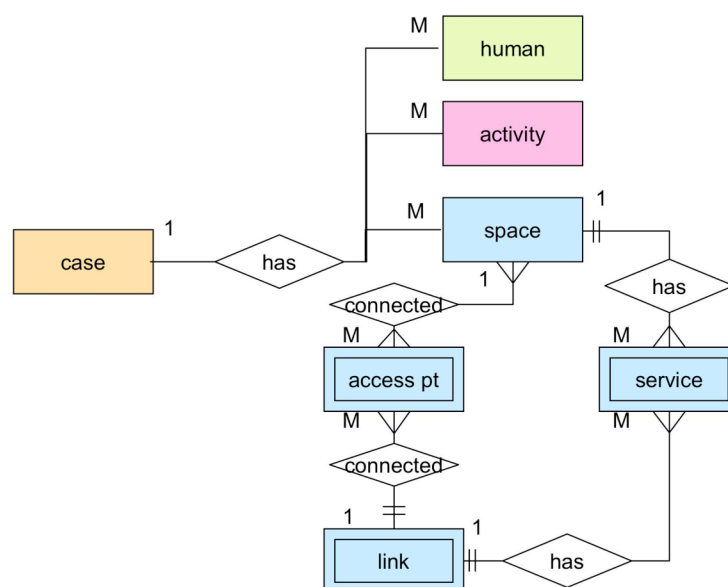


Figure 6.14: Entity relation diagram Human-Activity-Space ontology

E-R diagrams illustrate the logical structure of databases. In this sense they describe entities that are objects or concepts about which information is collected. A characteristic of E-R diagrams is cardinality, which specifies how many instances of an entity relate to one instance of another entity. In E-R diagrams relationships between entities are defined by relationship symbols. Entities for instance are often organised hierarchically so relations may be about level or may indicate that particular entities are ‘connected’ or ‘have (has)’ other entities attached. A one-to-one relation of the primary key (entity ID, in this case a unique case_id) groups all the entities pertinent to a particular case instance. In this sense a case is like a snapshot of a particular slice in time regarding human performance within a particular set of residential spaces.

As can be seen, a case contains the Human-Activity-Space extension. In other words, a single redesign case can have more than one human performer carrying out many activities in many spaces. This makes sense when we consider that the activity of reading a book can be carried out in a variety of spaces, anywhere from a bedroom to a toilet, or that activity of transferring might require more than one human performer, as in one provides care to the other. However the ability to do so successfully will be determined by the individual human performer's requirements in conjunction with aspects of a particular space. For instance, the provision of natural and artificial lighting, and presence of glare etc. become important in the context of the human's activity impairments.

As the extension builds heavily from the Accessible-Building model, it is not surprising that the spatial descriptors and arrangements are similar. In the extension, though, some relations are defined differently. For instance, a single 'space' entity can have many 'Services', 'Links' and 'Access Points'. An example, from residential design illustrates this point. It is not uncommon for a bedroom space to have several doors, say one connected to a external balcony, another to a walk in clothes storage area, while a third may lead to an adjoining hallway. In the same way, a single bedroom space can have many services attached to it; for instance, lighting and air-conditioning are not atypical.

Building from the Accessible-Building model means that all architectural facilities and their parts can be represented as a combination of spatial entities for the purpose of redesign to promote human ability. A major difference between the Accessible-Building model as originally conceived and the Human-Activity-Space extension is the notion that building redesign commences with human performer requirements resulting from activity limitations. Thus activity and human performance require explicit representation.

6.8 Human-Activity-Space model as a basis for redesign case description

Reasoning with redesign cases requires problem descriptions that capture the new redesign requirements in addition to capturing any existing building object descriptions. The extension of the Human-Activity-Space model facilitates this capturing of building redesign cases for the disability domain, as illustrated in Figure 6.15.

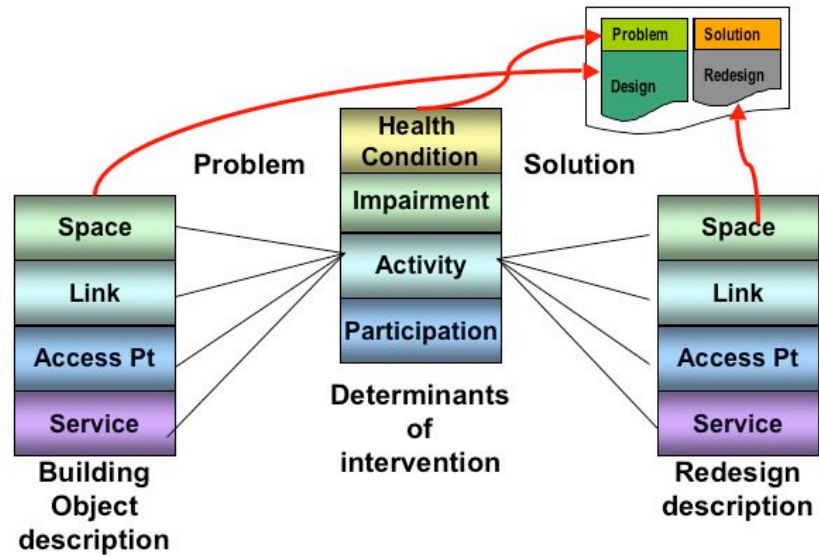


Figure 6.15: Capturing the knowledge domains in a CBR system

In the conceptual model, the problem formulation is represented by both the original building design and the determinants of intervention. The redesign solution is the result of this interaction and contains both the redesign description and the redesign transformation actions. The Accessible-Building model represents both the original and redesigned building descriptions, while the ICF framework represents the problem.

If we put this all together, we can see how entities derived from case-based design and redesign theory in combination with disability theory have been combined to create a new ontological model suitable for the purpose of redesign of architectural spaces for persons with disabilities. The new model provides some insight into the nature of redesign and provides a basis for computational formalisation. The redesign model developed here stresses the individuality of redesign while the model is flexible enough to accommodate multiple performers.

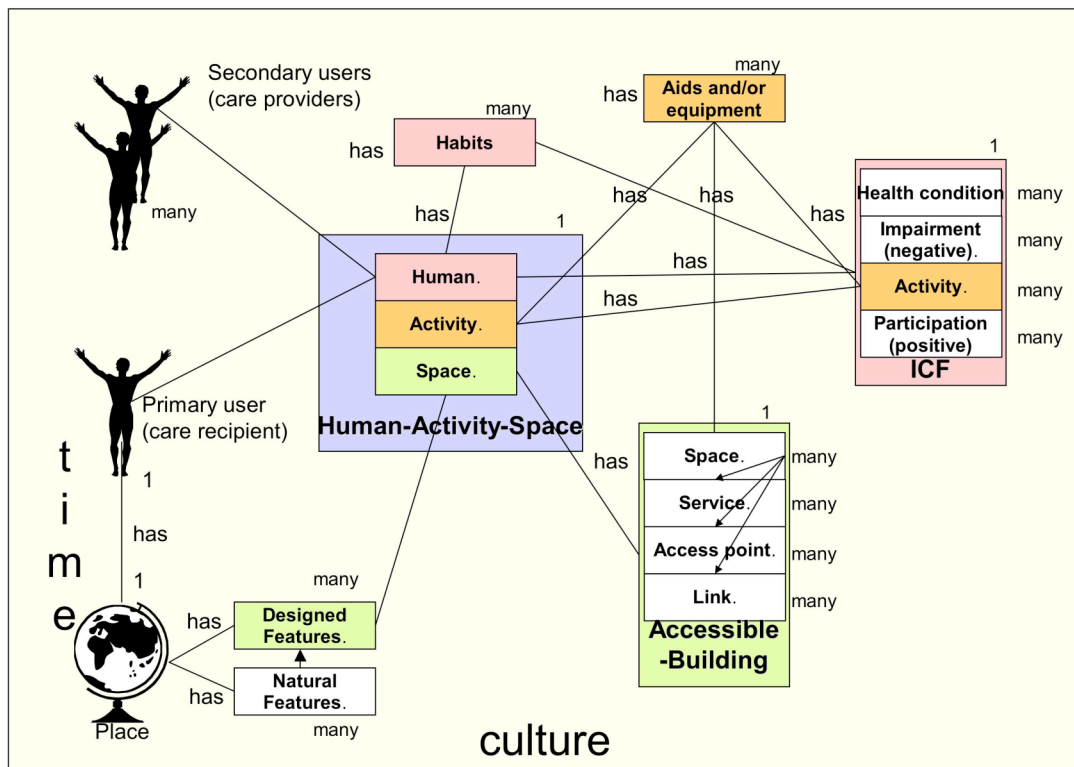


Figure 6.16: The Human-Activity-Space ontology demonstrating integration of conceptual constructs required to capture and reason with redesign cases for multiple performers.

As illustrated in Figure 6.16 the Human-Activity-Space model provides a means of integrating and representing the entities constructs required for CBrR. The intent to redesign a particular environment to make it more suitable for activity performance illustrates vividly the significance of context. Human activity is, after all, behaviour in a particular time and cultural context. Construction of buildings and performance of activities are shaped by culturally accepted forms and norms. For instance, the design of a toilet (e.g., squatting versus seated) and thus the activity of toileting varies, although the requirement for a human to eliminate waste does not. In CBrR these aspects are implicitly captured as a case instance. In other words, the case contains all the relevant features embedded in a particular cultural context at a particular point in time.

6.9 Reflexive Summary

This chapter presented the Human-Activity-Space model that provides the basis for the terminological foundations underpinning any development of computational formalisms. The model is an action-based response designed to provide the basic representation model for home modification. This must then be integrated with the conceptual model of CBrR presented in chapter four. The Human-Activity-Space model integrates and extends current theoretical understandings based on the compositional requirements of case-based home

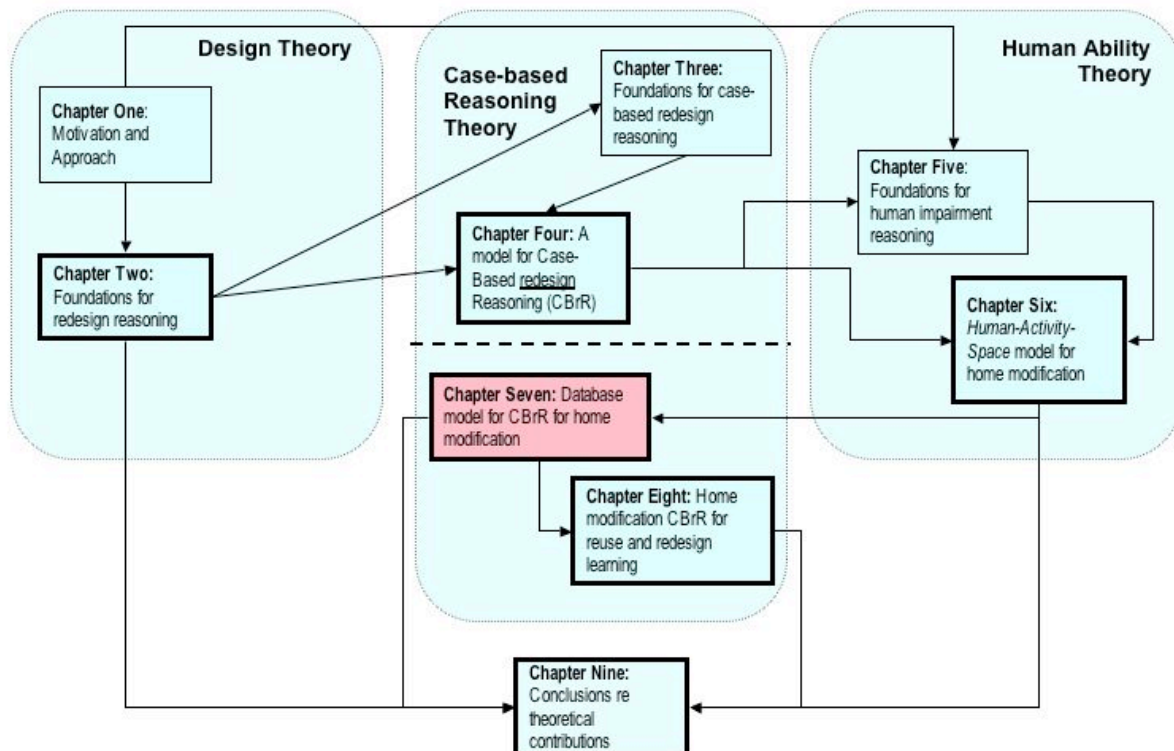
modification specific redesign practice. The exploration, analysis and synthesis of conceptual materials undertaken within this chapter assists in illuminating critical aspects of previous theoretical understandings that are insufficient in relation to redesign representation.

Specifically the contributions outlined in this chapter are as follows.

- ▶ The starting point of a redesign query demands building feature descriptions that create an environment for human activity. Incorporating and extending Activity-Space features facilitates this by consideration of activities and their corresponding building spaces.
- ▶ The lack of any spatial model that incorporated accessibility lead to the development of the Accessible-Building model. Four critical groups of accessible entities comprise the Accessible-Building model. This model encapsulates and groups particular aspects of the built environment relevant to human impairment and draws on interdisciplinary knowledge from facilities management, occupational therapy and building design/redesign.
- ▶ Incorporating, combining and extending the Activity-Space model with the Accessible-Building model provided formalised knowledge blocks that serve to describe and link building design, requirements, components and relations that include variation in human performance.
- ▶ Formalisation and reconceptualisation of the necessary knowledge blocks evolved into the Human-Activity-Space model, a major contribution of this research.
- ▶ The Human-Activity-Space model has potential application to both design and redesign as a framework to describe and evaluate building performance and building outcomes for the whole range of human users.

Most significantly ontological description of the constructs, entities and their attributes provides the structure and functionality required by a computational redesign reasoning application. The terminological model foundation provided here provides guidance for computational technology

7



Database model for CBrR for home modification

Chapter 7: Database model for CBrR for home modification

7.1 Introduction

In selecting a Web platform and database management system (DBMS) for the implementation of a CBrR, a primary consideration is the overall purpose. In this case, the sole purpose is to represent and store a case-knowledge base that can be accessed anywhere and that is dynamically interactive rather than static in nature. This chapter therefore sets out to answer the question posed by exploring: *what a Human-Activity-Space relational database specification might look like?* In CBR, one of the major issues is the representation of case-knowledge or episodic knowledge. The development of a storage system for a case-knowledge base is an important aspect of the research into development of any case CBR model but particularly so for CBrR as representation needs differ.

Case-knowledge, in this instance, is the data related to housing redesign for persons with disabilities. For this to be adequate, client (human), activity and housing (space) case-knowledge has to be linked and represented in a flexible way. The Human-Activity-Space model elucidated in chapter six provides the conceptual model required for this flexible implementation. For example, it provides a structure for organising case data and enables case-knowledge to be retrieved from the case library so that it can be browsed, retrieved and reused. In this way, existing case-knowledge can be made explicit and old redesign cases and/or case pieces can be reused.

The focus of this chapter is thus the articulation and development of relevant knowledge items including the grouping and ordering required for incorporation into an application specific CBrR system. This chapter further elucidates the computational formalisms employed to create a representational ontology for a CBrR capable of representing and integrating human ability, activity and built environment knowledge.

7.2 Chapter Structure

This chapter overviews the framework employed for hypermedia case representation in a *HMMinfo casestudies* CBrR prototype. First, this chapter explores the specifics required of a housing redesign application focus. Second, it applies the redesign data model presented in chapter four to an online computational environment. The generic CBrR representation formalisms presented in chapter four are revisited and reviewed to clarify implications for a housing redesign domain computational implementation.

Finally, the Human-Activity-Space data model developed in chapter six is presented as an online or web-based, relational database implementation. Consequently, web specific design and database structures, relevant to a Web implementation methodology are described. In articulating Web implementation, the major issues addressed concern formalisation of the means for representing and incorporating relevant human impairment housing redesign knowledge into the CBrR application. In this manner, the domain understanding articulated in chapters five and six becomes the foundation for a computational framework that provides a more formal description than would normally apply to the domain (Gardner, Rush, Crist, Konitzer, & Teegarden, 1998).

7.3 Representation of Home Modification and Maintenance redesign cases

In carrying out redesign interventions the primary roles that service providers within NSW have are twofold first, assessment of need; and second, the provision of either a modification or a maintenance intervention (HACC and Ageing Programs Unit, 2000). The Home Modification and Maintenance case-types provide a means of capturing a housing occupancy lifecycle where assessment, modification and maintenance interventions can be captured and layered over time in a flexible manner. Figure 7.1 illustrates this idea.

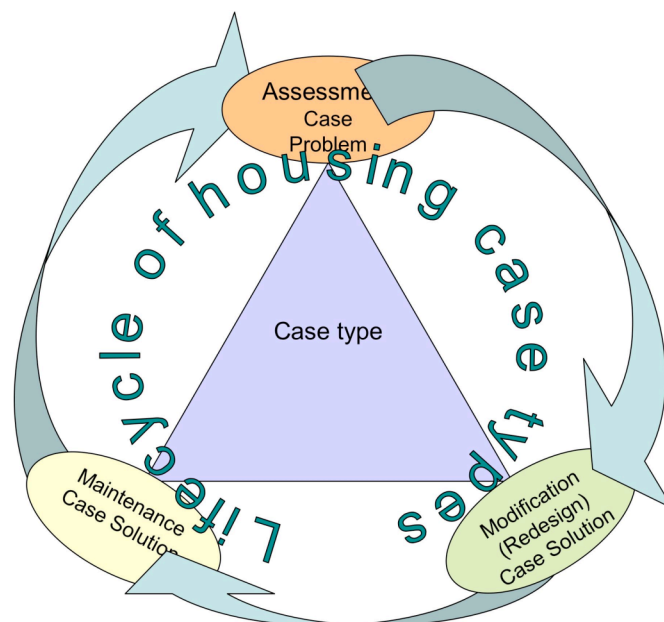


Figure 7.1: Lifecycle or relationship between case types

7.4 Home Modification and Maintenance case-study a CBrR prototype implementation

The primary data need for a housing redesign case base that is to be used as part of a CBrR is the ability to represent and store data in such a way that it is possible to extract previously

stored housing redesign cases. This requires that cases have predetermined elements and that these can be used between old and new housing redesign cases. The case-based representation structures selected are designed to facilitate the following implementation goals:

- ▶ to relate the original housing assessment, modification and maintenance features to the redesign (modification) variables;
- ▶ to isolate individual human (person), activity and housing (space, access point, link & services) elements in each case so browsing and reuse are facilitated;
- ▶ to relate identified features of existing case documentation to case acquisition; and
- ▶ to be able to extract redesign knowledge from redesign cases to learn about housing redesign.

The description of redesign cases for the domain of Home Modification and Maintenance requires that case types be defined according to the goal of intervention. The decision to partition the prototype case-library into three case types (i.e. assessment, modification and maintenance) stemmed from the need to logically distinguish interventions being provided. This distinction is crucial for HMM case classification because, although the majority of cases may have both assessment and modification parts, not all cases will. In fact, some assessments will reveal that redesign is infeasible and relocation may be preferable instead. In addition clients may have issues associated with ‘denial of disability’ (Fuhrman, 2001; Katz, Fleming, Keren, Lightbody, & Hartman-Maeir, 2002) and thus may not agree to all the redesign work identified as helpful. In addition, the assessment case-type can be distinguished by its focus on the functional implications for human occupants of the current environmental setting. Furthermore, the assessment case-type is primarily the responsibility of occupational therapists.

On the other hand, the modification case-type focuses on the environmental implications of modification and is primarily the responsibility of construction industry personnel. This means that the information contained within the two case-types, while having similar representation needs, differs in focus. For instance, assessment case-type data will have a greater emphasis on ‘problem sensing’ but modification and maintenance, because they are about problem validation, will contain greater construction detail and actual, not just anticipated, material and labour costs.

Last, but not least, the maintenance case-type contains information about interventions designed to maintain a particular functional outcome. Figure 7.2 illustrates the three case-

types and shows how they each contain the three Human-Activity-Space model knowledge components.

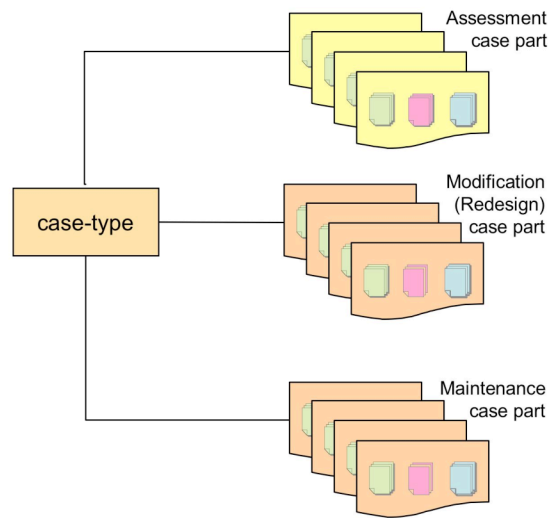


Figure 7.2: Case-types relevant to Home Modification and Maintenance services

The creation of housing redesign case-types based on HMM service types enables maximum specificity for browsing and reuse. Data needs to be stored in such a way that HMM interventions (i.e. assessment, modification and maintenance) can be linked and/or reused. System design has to satisfy HMM consumers and service providers' retrieval needs. In other words, the ability to match data between individual persons (i.e. humans), their impairment and participation needs, on the basis of similarities and differences in activity, and housing spaces. The relationship between case-contents and case types is illustrated in Figure 7.3. It also makes clear that aspects of the Human-Activity-Space model are how the design, problem, redesign and solution components are represented and stored.

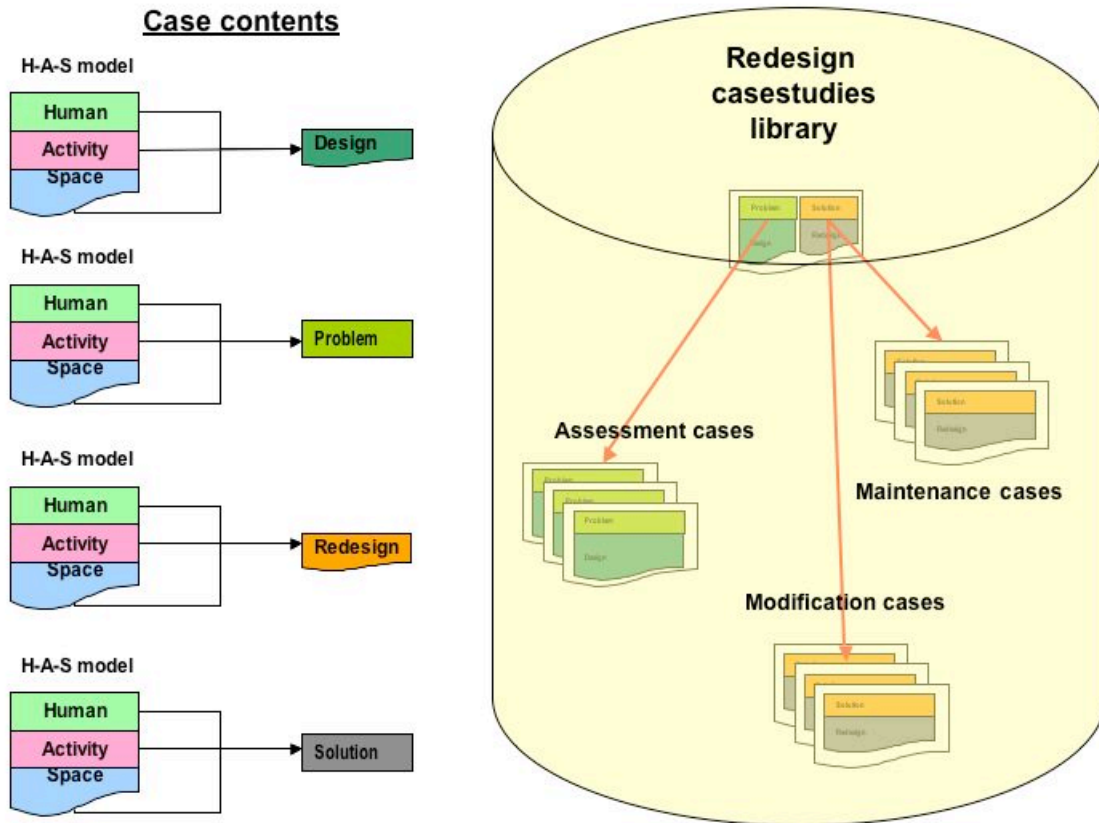


Figure 7.3: HMMinfo prototype casestudies library showing integration of the H-A-S and CBrR models

In order to achieve the necessary browsing and retrieval functionality, articulation of the existing design, new requirement and/or redesign solution must be achieved. The groundwork for this formulation was outlined in chapter four where the redesign case formalism was defined symbolically as the triplet $C^r = \{C^{rp}, C^d, C^{rs}\}$ where C^{rp} is the new redesign problem description, and C^d is the existing design description, and C^{rs} is the redesign solution description. We can now extend this to incorporate the Human-Activity-Space model developed in chapters five and six for further illustration and clarification.

For instance, our housing assessment case-type scenario might commence when an older person is referred for an assessment following a fall within their bedroom. The assessment task then becomes one of integrating the new requirement of preventing another fall in the bedroom for a person with an impairment of motor coordination into an existing home. Using the redesign formalism articulated in chapter four and restated above, we can now describe both our assessment case components and the full case-type description as follows:

7.4.1.1 Human impairment housing assessment case component representation

$$C^p = \{\{\text{incoordination (person), passing_through (activity), with_carer (activity habit), electric_wheelchair (equipment), main_bedroom (space), widen_doorway (accesspoint),...}\} \text{RedesignRequirement}\}$$
$$C^d = \{\{\text{bedroom_wall_partition (space), door_hinged (access point),...}\} \text{HomeDescription}\}$$
$$C^{rs} = \{\{\text{Case1_incoordination (person) } \rightarrow \text{Case2_balance (peson), Case1_main_bedroom (space) } \rightarrow \text{Case2_lounge (space), Case1_bedroom_wall_partition (space) } \rightarrow \text{Case2_lounge_wall_partition (space), Case1_door_hinged (access point) } \rightarrow \text{Case2_door_removed (access point),...}\} \text{RedesignSolutionDescription}\}$$

Note: The redesign solution component (C^{rs}) of an assessment case-type is a result of case-based reuse. In other words it is evident only when an assessment case is reused either for the same person at a later point in time or for another person with a similar home, activity set or impairment type.

7.4.1.2 Human impairment housing assessment type case description (for original case entry)

$$C^r = \{\{\text{incoordination (person), passing_through (activity), with_carer (activity habit), electric_wheelchair (equipment), main_bedroom (space), widen_doorway (accesspoint),...}\} \text{RedesignRequirement} \{\text{bedroom_wall_partition (space), door_hinged (access point),...}\} \text{HomeDescription}\}$$

If we reflect back to the idea of a lifecycle of housing case-types, the modification case-type might commence following on from any assessment recommendations but after funding approval. It differs from the assessment case-type in that it does not contain any recommendations not agreed for action. Thus the modification case may contain less redesign than the assessment case-type due to differences between need and want resulting from client preference and/or access to financial assistance. Using the same redesign formalism we can formalise our modification case components and case-type description as follows:

7.4.1.3 Human impairment housing modification case component representation

$$C^{rd} = \{\{\text{bedroom_wall_partition-1000mm (space), door_sliding (access point),...}\} \text{RedesignHomeDescription}\}$$
$$C^{rs} = \{\{\text{assessment_passing_through_impossible (activity) } \rightarrow \text{modification_passing_through_independant (activity), assessment_main_bedroom (space) } \rightarrow \text{modification_main_bedroom (space), assessment_bedroom_wall_partition-600mm (space) } \rightarrow \text{modification_bedroom_wall_partition-1000mm (space), assessment_door_hinged (access point) } \rightarrow \text{modification_door_sliding (access point),...}\} \text{RedesignSolutionDescription}\}$$

7.4.1.4 Human impairment housing modification type case description

$$C^r = \{ \{ \text{bedroom_wall_partition-1000mm (space), door_sliding (access point), ...} \}$$
$$\text{RedesignHomeDescription} \{ \text{assessment_passing_through_impossible (activity)} \rightarrow$$
$$\text{modification_passing_through_independant (activity), assessment_main_bedroom (space)} \rightarrow$$
$$\text{modification_main_bedroom (space), assessment_bedroom_wall_partition-600mm (space)} \rightarrow$$
$$\text{modification_bedroom_wall_partition-1000mm (space), assessment_door_hinged (access point)} \rightarrow$$
$$\text{modification_door_sliding (access point), ...} \}$$
$$\text{RedesignSolutionDescription} \}$$

The housing maintenance case-type might commence following damage to the original design components or as a response to repeated exposure resulting from usage by a person with an impairment of motor coordination. The maintenance case contains only information relevant to the repair of existing building components. However the same redesign formalism can also be satisfactorily applied to describe any maintenance case components and the resulting case-type description as follows:

7.4.1.5 Human impairment housing maintenance case component representation

$$C^{rd} = \{ \{ \text{bedroom_wall_partition (space), door_frame_foam buffer (access point), ...} \}$$
$$\text{HomeDescription} \}$$
$$C^{rs} = \{ \{ \text{modification_door_frame_wood (access point)} \rightarrow \text{maintenance_door_frame_foam buffer (access point), , ...} \}$$
$$\text{RedesignSolutionDescription} \}$$

7.4.1.6 Human impairment housing maintenance type case description

$$C^r = \{ \{ \text{bedroom_wall_partition (space), door_frame_foam buffer (access point), ...} \}$$
$$\text{HomeDescription} \{ \text{modification_door_frame_wood (access point)} \rightarrow \text{maintenance_door_frame_foam buffer (access point), , ...} \}$$
$$\text{RedesignSolutionDescription} \}$$

In this manner, it is evident that the redesign formalism developed in chapter four has the power and flexibility to adequately represent the required human impairment redesign knowledge needed to reason with Home Modification and Maintenance cases. The major difference between this representation and the teaspoon redesign example provided in chapter four stems from the fact that residential redesign for persons with disabilities requires considerably greater knowledge.

Making human (individual person), activity, home and room (space) components explicit in redesign representation formalisms enables both ‘problem sensing’ and ‘problem validation’ across the three most common HMM intervention case-types. Figure 7.4 more clearly illustrates the variance in focus within the Human-Activity-Space model knowledge feature contents within the three case types. For instance in *assessment*, the focus on the person concerns the degree of impairment, but in *modification* and *maintenance* case-types the focus shifts to the degree of enhanced participation. Similarly, in the assessment case-type the focus is on activities impaired but in the modification and maintenance case-types it is on activity

participation. The spatial components in the housing formalisation include the home and any other spaces (rooms) of concern. The focus within these case-types also differs with assessment focusing on problems, modification focusing on solutions and maintenance focusing on component integrity.

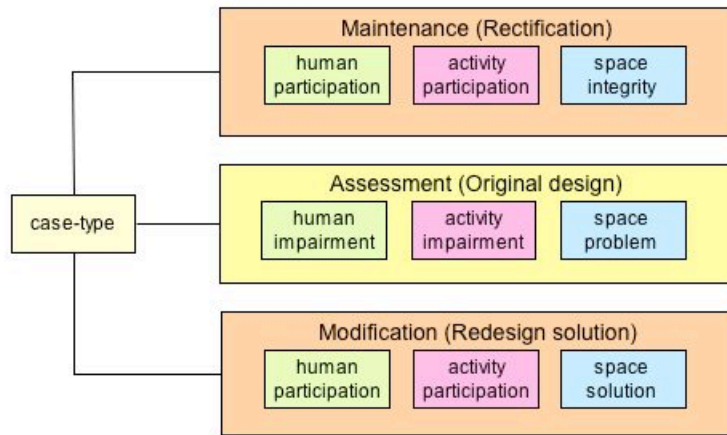


Figure 7.4: Comparison of Human-Activity-Space relevant content within case-types

As mentioned in chapter four providing more structured browsing enables case acquisition and browsing based on all the case-type classes provided. Thus the implementation of housing redesign case-types permits the user to browse across other similar case-types to obtain an overview of differences based on Human-Activity-Space component relationship descriptions. In addition, inclusion of HMM case-types enables cross-type case linkages and builds on the CBrR for Human impairment understandings already provided. Figure 7.5 demonstrates this flexibility by illustrating how the three Home Modification and Maintenance case-types can be combined and reused.

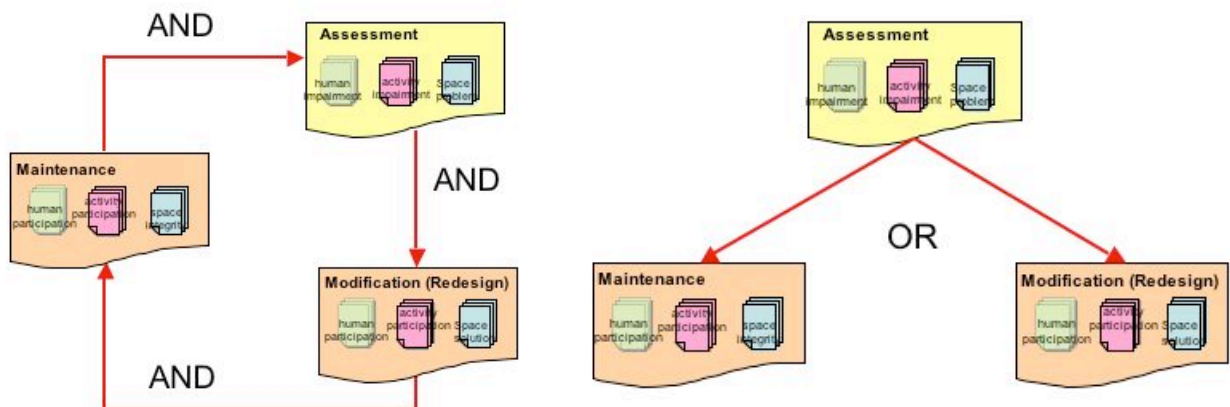


Figure 7.5: Case-types enable maximal flexibility in linkage and part reuse

For instance, an assessment intervention may provide the basis for a modification or a maintenance intervention. It is also possible that a modification intervention might at a later

date require a maintenance intervention. An example of how this might occur, would be if the bathroom contained a glazed tile floor with a coefficient of friction of less than the desired 0.6 (e.g. 0.3) and this was assessed as being problematic for the human abilities required for the activity of safe transferring. The typical modification intervention of applying a non-slip tile coating must be maintained for the intervention to remain effective over time. Consequently, a follow up maintenance intervention such as a non-slip recoat may also need to be applied.

The separation of case-types allows cases to be a snapshot of a particular intervention at a particular point in time. For instance, home modification can be a lengthy process and there may be a significant time lag between assessment and modification and between modification and maintenance. If we go back to our non-slip bathroom floor coating example for illustration, there may be anything from a one to eight week gap between the assessment and modification intervention due to the time needed for consultation, contracting, not to mention funding and planning approval. However, maintenance interventions are generally carried out according to manufacturers specifications and floor recoating may not need to be carried out for another two to ten years depending on product, and perception of risk based on frequency of use and/or cleaning regime.

7.4.2 Impact of computational implementation environment on access, dynamism and syntax

For a CBrR system to be accessible to its intended user audience, the CBrR system being designed requires selection of computational technologies that are independent of operating systems and that do not require large amounts of memory. At its most simplistic, a Web platform allows users' to locate a website using the HyperText Transfer Protocol (HTTP) and to browse static information using Hyper Text Mark-up Language (HTML). However Web browsers (i.e. Netscape, Microsoft Explorer etc.) can do much more. They can connect intranet and Internet networks while handling presentation of data demanded dynamically via a communication protocol from a web server (Muller, 1999).

In developing the prototype *HMMinfo casestudies* CBrR for the Home Modification and Maintenance Information Clearinghouse, it was assumed that cross-platform accessibility was necessary to permit the case-base to be accessed and used via the Web. Current Web browser software enables connection to a web server that then can act as a client of a database server (which may or may not be running out of the same hardware box). A multi-tier approach enables application partitioning (breaking up application code into modules) to enable cross platform accessibility.

Figure 7.6 illustrates the dynamic approach chosen for the *HMMinfo casestudies* prototype implementation. Interactivity is provided via a Common Gateway Interface (CGI), in other

words, a standard for interfacing external applications with information servers, such as HTTP or Web servers. A plain HTML document that the Web daemon retrieves is static, which means it exists in a constant state (e.g. a text file that does not change). A CGI program, on the other hand, is executed in real-time, so that it can output dynamic information. In this case, a combination of CGIs and Structured Query Language (SQL) allows the linkage of a backend case information storage database to the Web, allowing anyone with access to the Web to query it. Use of computational scripting programs enable a web server daemon to transmit query information to our database engine, and receive the results back again so they can be dynamically displayed to the end user.

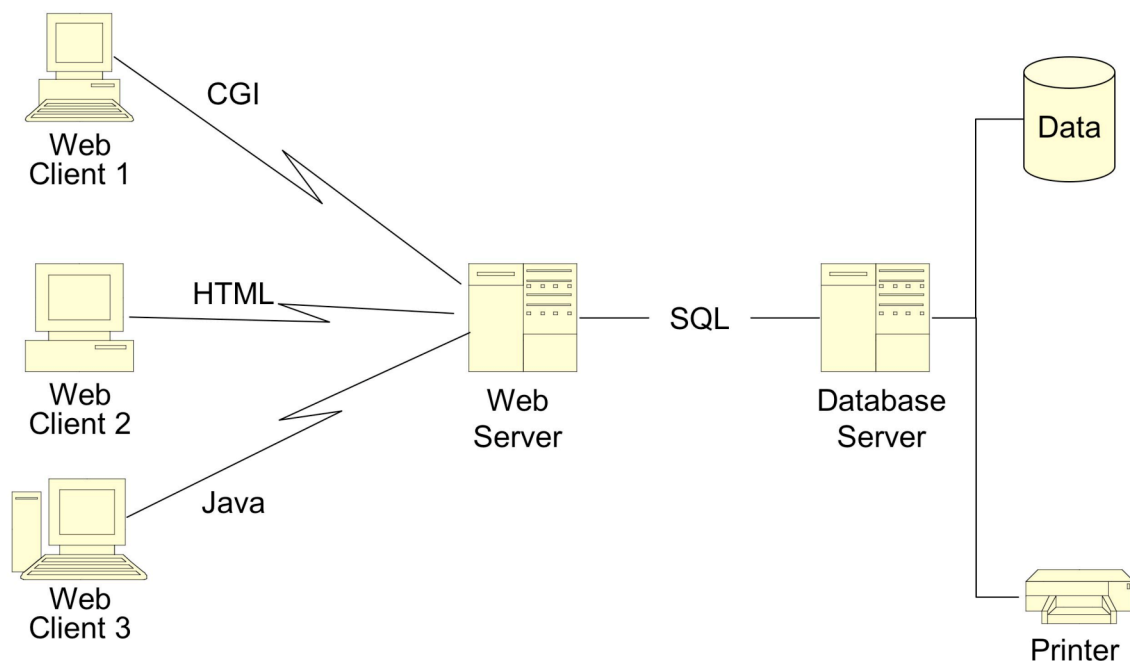


Figure 7.6: A typical web-based Client/Server system (Muller, 1999, p. 27)

HTML forms facilitate collection of information via a system of elements that include text fields, pull down selection menus, buttons and multiple choice text boxes (Hubell, 2000). Creating dynamic web pages requires that session variables are captured by cookies and operated on using computational program scripts. The actual programming languages used were: ColdFusion Professional Version 5 (this does the majority of web-smart programming) and Javascript (for form validation). Javascript was chosen over Java as the Javascript source code can be directly interpreted by a web browser with the code being either directly embedded in a HTML page or referenced in a separate file (Lemay & Moncur, 1996). In addition, a free-ware program called 'Image Magick' working with ColdFusion was used to automatically create thumbnails of multimedia and graphic files associated with cases.

The computational programs used enabled web-based Server Side Includes (SSIs) to pull data from the web server and/or a database system dynamically (Hubell, 2000). Dynamic or 'live' casestudy web pages thus display the specified database fields and any relevant system variables like the time and date a file was last modified. In the *HMMInfo casestudies* prototype, all attribute values in the case forms (e.g. radio buttons, dropdown boxes, etc.) are retrieved from the database server. The value of the 'created' field is taken from the web-server when the case is being created by a user (typically a home modification service provider) and stored in the backend database. The user's details or case-study 'creator' values are taken from the agency name identification provided by the end user provided when they subscribe and remembered when they log into the prototype.

7.4.3 Reducing Entity-Relationship (E-R) diagrams to relational tables

The E-R diagram on which the *HMMInfo casestudies* prototype is based was presented in Chapter six (Figure 6.14). The E-R diagram provided the basics for a data model conceptual schema, in terms of entities, attributes, relationships between entities, participation and cardinality ratios (Hughes, 1991, Ullman & Widom, 2002). As Muller (1999) and Simson & Witt (2001) make clear, most database designs stem directly from E-R diagrams because this abstraction reduces complexity and facilitates focus on entities (objects or things) and the relations between them. Thus the Human-Activity-Space model presented in chapter six provided the basic information about relevant entities and their relationships.

However it required further extension to fit the housing redesign domain. The significance parts of the housing redesign domain extension included the need to capture additional data about the HMM service agencies providing the cases, the informal and formal carers of the care recipient and the home in addition to the basic categories already described and presented. An agency has multiple cases and collecting data about the agency means that a login system can reuse this data to provide privileged access to registered users' and enables the case-library to collect this data only once and then to recognise the agency automatically reusing data. Additionally, the extension needed to enable incorporation of multiple carers and spaces. Consequently, Figure 7.7 has a primary care recipient who has a number of carers. Similarly a home has multiple spaces.

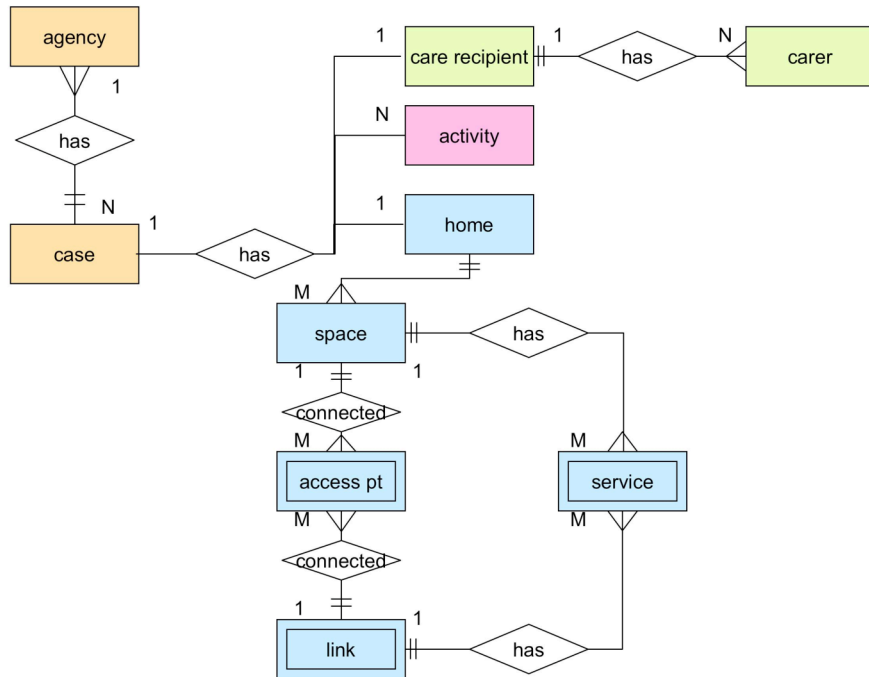


Figure 7.7: Extension of the basic Human-Activity-Space model to accommodate Home Modification and Maintenance cases

Based on the Human-Activity-Space housing extension E-R diagram, sets of unique tables were created. As in all relational databases within each table, a row represents a relationship amongst a set of values having particular mathematical and/or other properties. For instance: (Unique-case-number: integer, Name: string, Case Type: string, Case-File-number: integer).

In general, a relational schema (logical design of the database) is a list of attributes and their corresponding domains. Domains in the *HMMinfo casestudies* prototype were defined into six tables based on the housing redesign E-R diagram prior to normalisation as follows: (Agency, Case, Person, Activities, Home, Users).

7.4.4 Choice of a Database Management System (DBMS)

For the purpose of prototype implementation Microsoft Access was the Database Management system (DBMS) selected to use as the backend to online dynamic web implementation. In Microsoft Access this is achieved by definition of multiple tables and these are then combined with database query procedures to produce a relational data model that can be implemented on the Web. Microsoft Access is designed to respond to SQL commands, which are automatically optimised to facilitate queries. SQL enables a user to interact with a database. Queries on the 'Access' database corresponds to SQL standard language and thus support for a restricted set of domain data types including fixed length character strings, integers and fixed and floating point numbers was provided (Korth & Silberschatz, 1991).

The fact that Server Side Includes (SSIs) and Javascript computational programs can be integrated is an important consideration in the selection of a case knowledge base for a CBR application. This is because other elements of the CRrR system like retrieval and reuse algorithms can be developed separately and then linked to the case knowledge base. Because the cases stored need to be dynamically stored and retrieved the database contents will change over time as case information is stored, reused and/or deleted. Thus the collection of case information stored within the *HMMinfo casestudies* database at any particular point of time is simply an *instance* of the cases within the database.

7.4.5 Case representation within the DBMS

As Korth & Silberschatz (1991) make clear, a DBMS can be defined as consisting of a set of interrelated data in combination with set of computational programs designed to access that data. Relational databases representation requires that case content data is translated into a collection of base tables that are comprised of rows and columns (relations) and views (Muller, 1999). Thus case-type representation structures already outlined using set notation need be translated to relational database notation for implementation purposes. Table 7.1 illustrates this translation process for redesign case descriptions from set notation to database notation.

Table 7.1: Demonstration of translation from set notation representation to database readable representation structures for a modification case-type

Case contents	Example using set notation	Example using database notation
Redesign HMM problem (C^p)	{ {incoordination (person), passing_through (activity), with_carer (activity habit), electric_wheelchair (equipment), main_bedroom (space), widen_doorway (accesspoint),...} RedesignRequirement }	{attribute-value ₁ ... attribute-value _n }
Redesign HMM space description (C^d)	{ {bedroom_wall_partition-600mm(space), door_hinged (access point),...} HomeDescription }	{table ₁ ... table _n }
Redesign HMM space description (C^{rd})	{ {bedroom_wall_partition-1000mm (space), door_sliding (access point),...} RedesignHomeDescription }	{table ₁ ... table _n }

Case contents	Example using set notation	Example using database notation
Redesign HMM solution (C ^{rs})	<pre> {{assessment_ passing_through_impossible (activity) → modification_passing_through_indepen dant (activity), assessment_main_bedroom (space) → modification_main_bedroom (space), assessment_bedroom_wall_partition- 600mm (space) → modification_bedroom_wall_partition- 1000mm (space), assessment_door_hinged (access point) → modification_door_sliding (access point),...} RedesignSolutionDescription} </pre>	<pre> (SQL_modifier-verb {attribute-value₁ ... attribute-value_n}) </pre>
Redesign HMM case (C ^r)	<pre> {{passing_through (activity), electric_wheelchair (equipment), incoordination (person), with_carer (activity habit), widen_doorway (accesspoint), main_bedroom (space)...} {bedroom_wall_partition- 600mm(space), door_hinged (access point),...} HomeDescription {bedroom_wall_partition-1000mm (space), door_sliding (access point),...} RedesignHomeDescription {assessment_ passing_through_impossible (activity) → modification_passing_through_indepen dant (activity), assessment_main_bedroom (space) → modification_main_bedroom (space), assessment_bedroom_wall_partition- 600mm (space) → modification_bedroom_wall_partition- 1000mm (space), assessment_door_hinged (access point) → modification_door_sliding (access point),...} RedesignSolutionDescription} </pre>	<pre> {{attribute-value₁ ... attribute-value_n} {table₁ {attribute- value₁ ... attribute- value_n}}, {table_n {attribute- value₁ ... attribute-value_n}} (SQL_modifier- {table₁ {attribute- value₁ ... attribute- value_n}-{table_n {attribute- value₁ ... attribute-value_n}}}) </pre>

7.4.6 Assumptions made in creation of base tables

In creating the database model for the HMMinfo casestudies implementation, a number of assumptions were made regarding the base tables. These are articulated as follows:

- ▶ that finite sets of values will exist for a number of attribute classes; for example, residential spaces of relevance can be adequately classified into a finite set of types such as Bathroom, Bedroom, Garden, Parking etc.;
- ▶ that a client could present on more than one occasion over time thus making it desirable for the case base to be flexible enough to reflect this possibility; and

-
- ▶ that person data tables are sufficiently extensible to include the care recipient multiple users' and/or care providers. Additional persons are represented as secondary clients, because their health, impairment status and anthropometrics will act as an additional constraint on the housing redesign (modification).

7.4.7 Database model

In the prototype *HMMinfo casestudies* implementation, the exact number of tables is determined in accord with predetermined mandatory and non-mandatory data fields. This results in considerable flexibility and enables each case instance entered to capture only the relevant person (human), activity and space details pertaining to that instance and case-type.

On careful examination of the original tables, it was apparent that a strategy to reduce redundancy and normalise the existing table schema was required (Simsion & Witt, 2001). Third normal form was chosen as it preserves dependency relations without unnecessary repetition compared with Boyce-Codd or fourth normal form (Muller, 1999). The tables correspond to the primary entities within the H-A-S model and illustrate the result of normalisation. Table relations are achieved by mapping of data values between tables using a unique ID.

Thus the record for each case instance is split between the common table (BaseCaseId) and the associated tables as illustrated in Figure 7.8. In general, a one-to-one relation of the primary key (entity ID, in this case the BaseCaseId field) connects all the basic H-A-S extensions. The exception to this is the Home table extensions that also have attached the Spaces and Links extensions (e.g., both these table types also have AccessPoints and Services extensions).

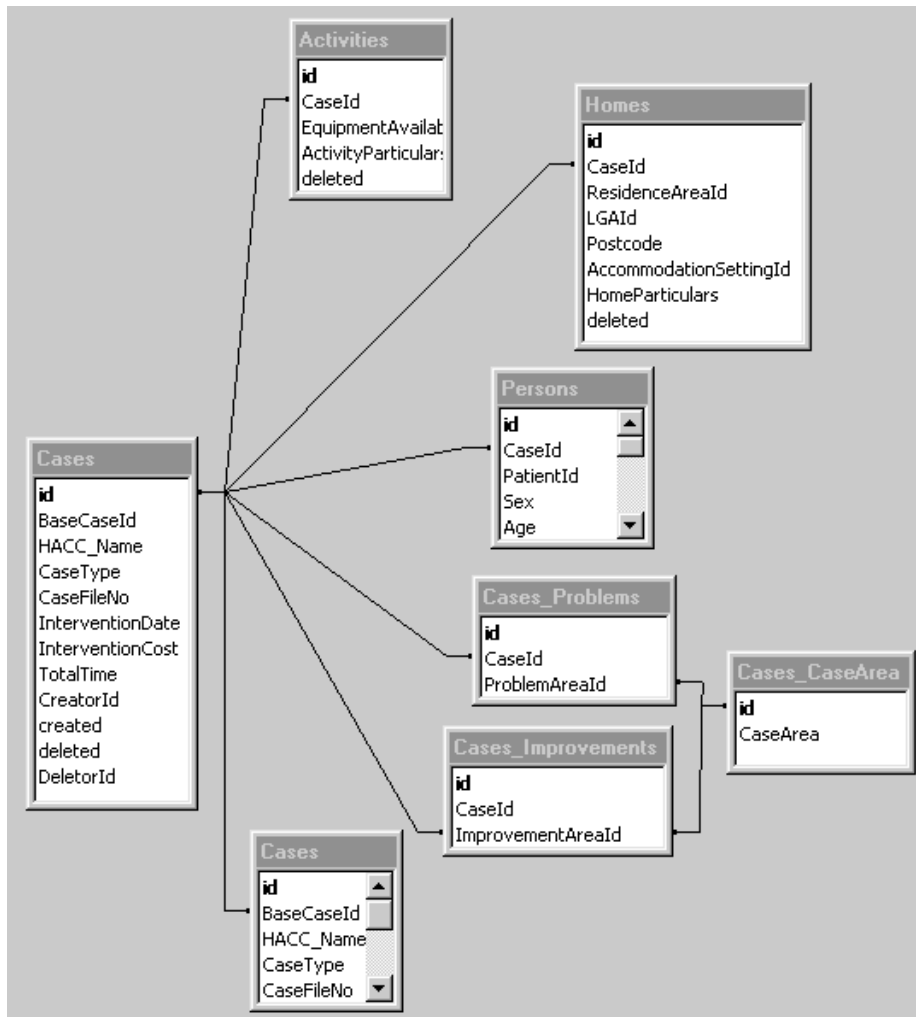


Figure 7.8: Entity-Relation diagram of the HMMinfo case organisation

A one-to-one relation of the primary key (entity ID, in this case the PatientId field) connects the case record for each instance with the corresponding human (person) data type tables. The table with the common attributes for ‘Human (person)’ is split between its common table and its corresponding type and severity tables as shown in Figure 7.9. Note there can be multiple persons (i.e. Person 1; Person 2; Person 3 etc.) with or without ability impairments. This enables details about all other persons sharing the same home space permanently or temporarily to be stored as a part of a case instance. That is, details about other persons apart from the primary client such as a partner, a carer, lodger or dependant child etc. can also be stored within the database schema.

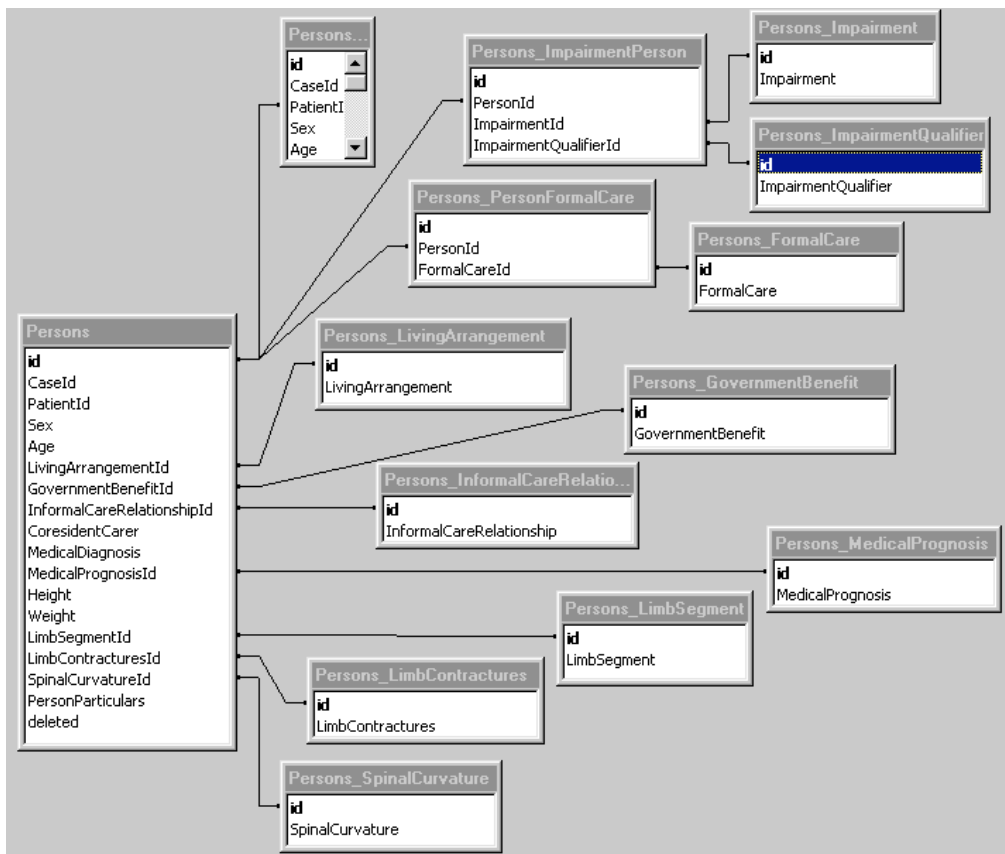


Figure 7.9: Entity-Relation diagram of human (person) component types

The table with the common attributes for activity is represented in the same manner (i.e. the record for each instance is split between the common activity table and the corresponding extension tables as shown in Figure 7.10). Note equipment (assistive devices) are part of this extension as are habits (activity particulars). The extension ‘activity particulars’, allows entry of data relating to the activity in free text covering features such as form of the activity, importance of the activity, frequency of the activity and meaning of the activity to the person etc.

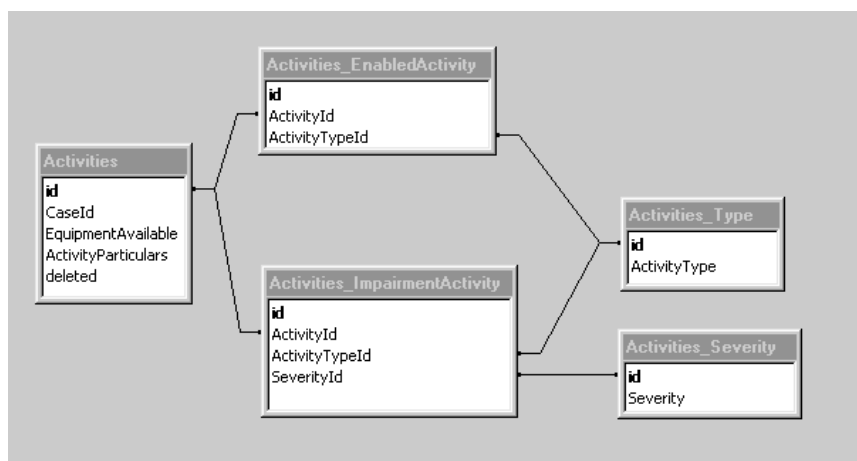


Figure 7.10: Entity-Relation diagram of activity component types

Only registered users' can reuse and submit cases. When a Home Modification and Maintenance service registers with the casestudy database a 'UserId' extension is stored. A one-to-one relation of the primary key (entity ID, in this case the 'id' field) connects the 'User' extension to the 'BaseCaseId'. The 'user' profile extension is represented by a maximum of n+1 tables, where *n* is the size of the group that it models. Thus the record for each user entity instance is split between the common user table and the corresponding type tables as shown in Figure 7.11.

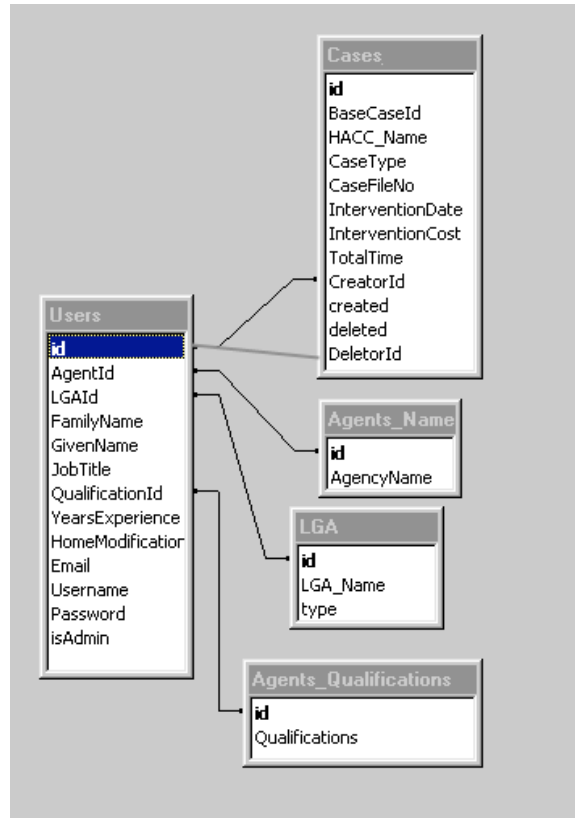


Figure 7.11: Entity-Relation diagram of 'Users' and their component types

A one-to-one relation of the primary key (entity ID, in this case the 'HomeId' field) connects the 'Home' extension to the 'BaseCaseId'. Thus the record for each case instance is split between the common table and the corresponding type table as shown in Figure 7.12

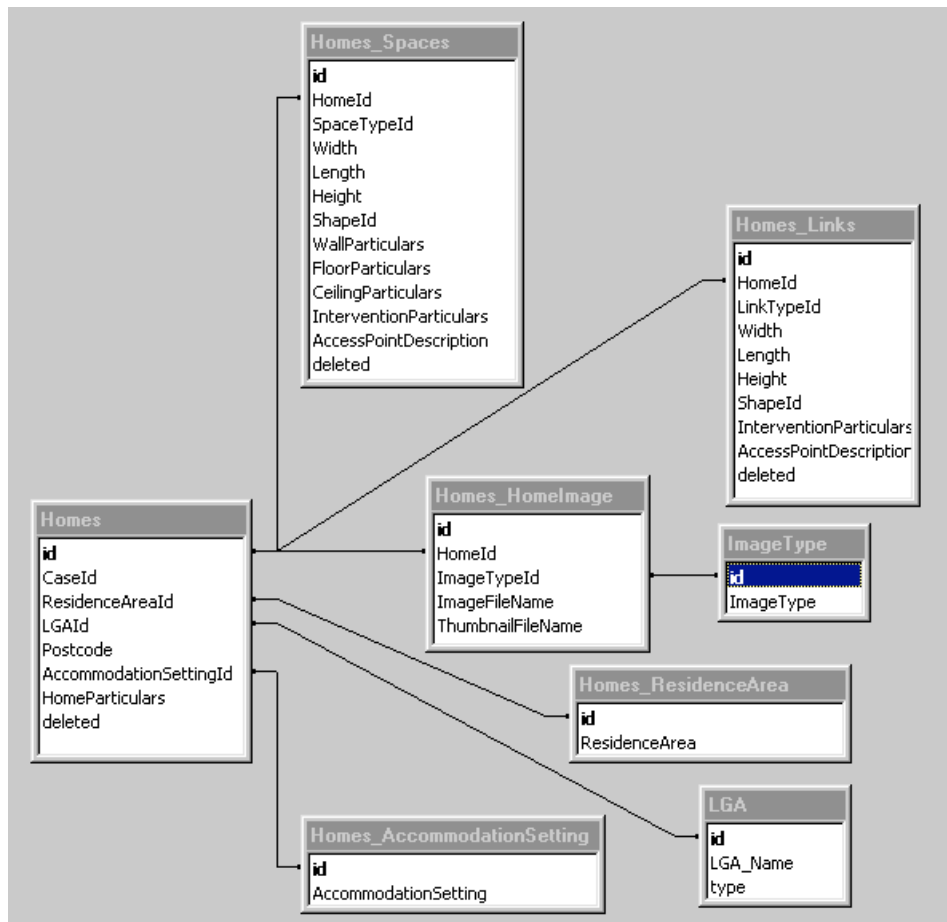


Figure 7.12: Entity-Relation diagram of homes and home component types

Each entity relating to the ‘SpaceId’ set of tables is represented by a maximum of $n+1$ tables, where n is the size of the group that it models. The record for each instance is split between the common table and the corresponding type table as shown in Figure 7.13. The ‘Space’ extensions ‘wall particulars’, ‘floor particulars’, ‘ceiling particulars’ and ‘intervention particulars’, allows entry of data relating to the space in free text covering features such as construction, materials, importance and meaning of the space and its wall, floor or ceiling structures to the person’s abilities etc.

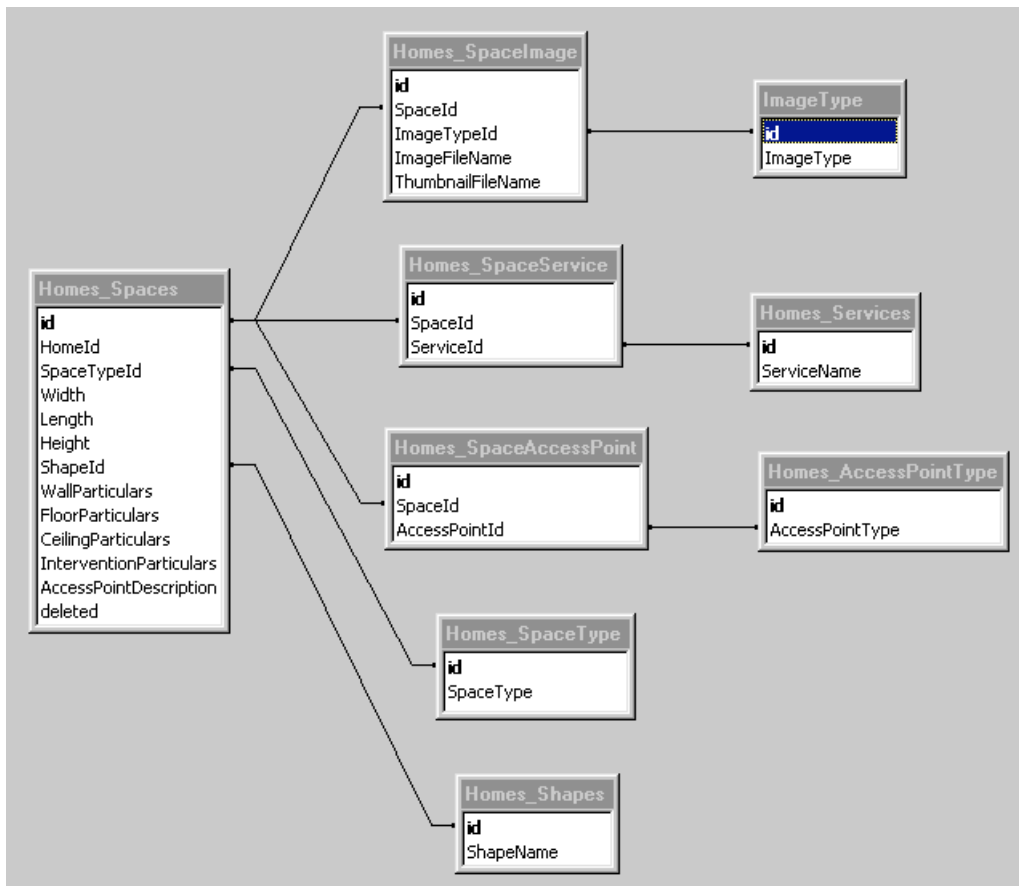


Figure 7.13: Entity-Relation table showing Spaces and their component types

Each entity of the 'LinkId' is represented by a maximum of $n+1$ tables, where n is the size of the group that it models. The record for each instance is split between the common table and the corresponding type table as shown in Figure 7.14. The 'Link' extensions labelled 'wall particulars', 'floor particulars', 'ceiling particulars' and 'intervention particulars', allows entry of data relating to the link in free text covering features such as construction, materials, importance and meaning of the link and its wall, floor or ceiling structures to the person's abilities etc.

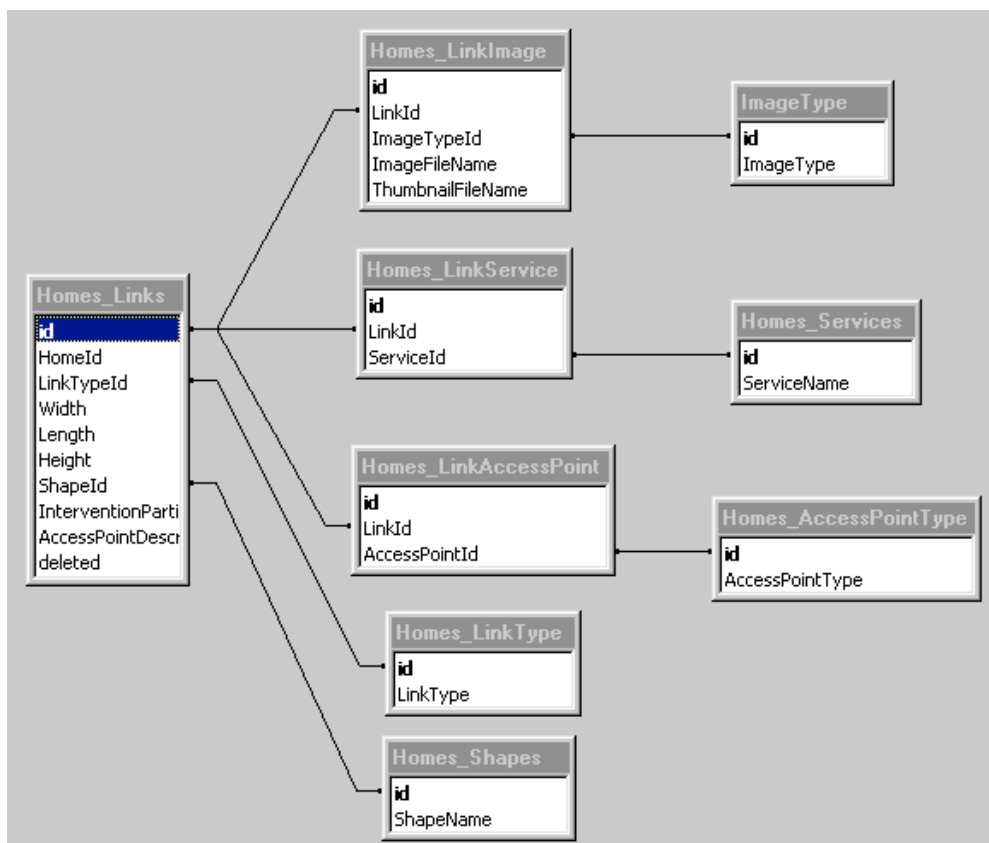


Figure 7.14: Entity-Relation tables showing Links and their component types

The final number database tables after normalisation into third normal form totalled forty-four.

The basic idea showing attributes common to the ‘human’ (person) extension within the Human-Activity-Space (H-A-S) model are presented in Table 7.2. A one-to-one relation of the primary key (entity ID, in this case the BaseCaseId field) connects the case record for each person instance with the corresponding data type table.

Table 7.2: Example of ‘human’ (person) entity type description

Human: Attribute Name	DB field	Field type	Attribute Domain
Name	name_id	character string	given_name, family_name
Sex	sex_id	boolean	‘m’ or ‘f’
Age_at_time of intervention	age_id	number	011 (e.g. any three whole numerical integers)
Primary Medical Diagnosis	med_id	character string	aids, acquired brain injury, addiction, allergy & asthma, alzheimer’s disease & dementia, amputation, amyloidosis, amyotrophic lateral sclerosis, ankylosing spondylitis, arthritis, attention deficit disorder, autism, birth defects, blindness, blood disorders, cancer & tumors, cardiovascular disorders, cerebral

Human: Attribute Name	DB field	Field type	Attribute Domain
			palsy, pregnancy, cystic fibrosis, deafness, depression, developmental disability, diabetes, digestive disorders, down syndrome, epilepsy, gauchers disease, traumatic head injury, incontinence, kidney disorders, leprosy, lupus, multiple sclerosis, muscular dystrophy, myasthenia gravis, osteoporosis, paget's disease, parkinsons disease, prader-willi syndrome, prostate disorders, psoriasis, psychiatric disorders, reye's syndrome, sjoren's syndrome, spina bifida, spinal cord injury, tay-sachs disease.
Impairment	imp_id	character string	balance or blackouts (vestibular), behavioural (self or other harming), child, cognitive (intellectual or learning), communication (loss of speech), disfigurement or deformity, emotional (mental), energy or stamina, extremes of size and weight, hearing (not corrected by aid), incoordination or tremor or balance, mobility (incomplete use of feet or legs), older, reach or dexterity (incomplete use of arms or fingers and/or difficulty gripping), sensation (numbness, pain or tingling chronic or recurring), universal or no obvious impairment, vision (not corrected by glasses)
Impairment qualifier	imp_q	character string	complete problem, mild problem, moderate problem, no problem, not applicable, not specified, severe problem

Table 7.3 illustrates how human (person) descriptions are represented as case instances within the database.

Table 7.3: Example of 'human' (person) entity case description

attribute 1: name_id	attribute 2: sex_id	attribute 3: age_id	attribute 4: med_d	attribute 5: imp	attribute n
bill_bloggs	m	73	multiple sclerosis	balance or blackouts (vestibular)	...
mary_bacon	f	42	kidney disorder	energy or stamina	...
belinda_crane	f	68	parkinson's disease	reach or dexterity (incomplete use of arms or fingers and/or difficulty gripping)	...
benjamin_telmud	m	5	developmental disability	cognitive (intellectual or learning)	...
human_m

Data types accommodated within the 'activity' extension are described in more detail in Table 7.4. A one-to-one relation of the primary key (entity ID, in this case the BaseCaseId field) connects the case record for each activity instance with the corresponding data type table.

Table 7.4: Example of ‘activity’ entity type description

Activity: Attribute Name	DB field	Field type	Attribute Domain
Activities impaired	act-imp	character string	bathing (or showering), bladder, bowel, dressing, feeding, finances, food preparation, grooming, housekeeping, laundry, medication, mobility, shopping, stairs, telephone, toilet use, transfer, transportation
Activity impairment severity rating	act-ty-r	character string	dependent, independent, independent with equipment, independent with verbal and/or physical prompt, physical assistance required
Equipment provided or available	equip	character string	wheelchair, scooter, prone trolley, traymobile, crutches, canes, toilet raiser, toilet surround, shower commode chair, perching stool, shower chair, electric toothbrush, electric shaver, bottom wiper, long handled comb, long handled brush, toe wiper
Activities enabled	act-en	character string	bathing (or showering), bladder, bowel, dressing, feeding, finances, food preparation, grooming, housekeeping, laundry, medication, mobility, shopping, stairs, telephone, toilet use, transfer, transportation

The attributes common to activity performance modelling and necessary for home modification reasoning are presented in Table 7.5 as they might relate to actual case instances.

Table 7.5: Example of ‘activity’ entity description

attrib. 1: act-imp	attrib. 2: act-ty-r	attrib. 3: equip	attrib. 4: act-en	attrib. n
bathing (or showering)	physical assistance required	toe wiper	feeding	...
bladder	independent with equipment	commode chair	finances	...
bowel	physical assistance required	bottom wiper	telephone	...
dressing	dependent	long handled comb	transfer	...
food preparation	independent with equipment	ergonomic knife	transportation	...
activity_m

The same idea is illustrated for ‘Home’ entities and is shown in Table 7.6. A one-to-one relation of the primary key (entity ID, in this case the ‘SpaceId’ field) connects the space type extensions of the H-A-S model.

Table 7.6: Example of home entity type description

Space: Attribute Name	DB field	Field type	Attribute Domain
Area of Residence	resid-a	character string	Africa, Asia, Australia (national), Australian Capital Territory, Europe, New South Wales, New Zealand, Northern Territory, Queensland, South Australia, Tasmania, United Kingdom, Victoria, Western Australia, United States of America
Local Government Area (LGA)	lga-h	character string	Armidale, Ashfield, Auburn, Ballina, Bankstown, Barraba, Bathurst, Baulkham Hills, Bega Valley, Bellingen, Berrigan etc.
Post Code (if in Australia)	pc	number- integer	postcode
Accommodation Setting	acc-s	character string	boarding house or private hotel, domestic-scale supported living facility, emergency or transitional accommodation, independent unit within retirement village, mental health, community care facility, private - mobile home, private - owned or purchasing, private - private rental, private - public rental, private home rented from aboriginal community, public place or temporary shelter, residential aged care facility, supported accommodation facility, temporary shelter within an aboriginal community
Spaces	sp_id	character string	bathroom or toilet or lavatory ensuite, bathroom or toilet or lavatory general, bedroom, dining, entry or atrium, garden, gym, kitchen, laundry, library, lounge, parking, patio, pool or spa, rumpus or family, shed, study or office
Access Points	ap_id	character string	doorway or gateway, gate, hinged door, sliding door, roller door
Links	link_id	character string	bridge or berm, corridor or pathway, landing, lift, ramp, stair, threshold
Services	serv_id	character string	electricity, furniture, garbage, lighting, mail, plumbing, product, rail, telecommunication

Table 7.7, shows how the spatial (environmental) entity descriptions might be represented as case instances within the actual *HMMinfo prototype* database.

Table 7.7: Example of space entity case description

attrib. 1: resid-a	attrib. 2: lga-h	attrib. 3: pc	attrib. 4: acc-s	attrib. 5: sp_id	attrib. n
New South Wales	Hunters Hill	2110	private - owned or purchasing	bathroom,	...
Victoria	Melbourne	3000	boarding house or private hotel	lavatory or toilet	...
New South Wales	Parramatta	2700	private - owned or purchasing	kitchen	...
South Australia	Adelaide	8000	residential aged care facility	laundry	...

attrib. 1: resid-a	attrib. 2: lga-h	attrib. 3: pc	attrib. 4: acc-s	attrib. 5: sp_id	attrib. n
environment_m

In CBR each case instantiates a particular set of features that are stored in a case library. The term *case-library* describes a special database that stores a large amount of case files (Kolodner, 1993). As can be seen from examination of the entity case description tables above, the case descriptions within each case instance contain only the entity values relevant to it. The DBMS has been designed in such a way that not all fields are mandatory nor is it necessary that all cases have components of all case types. The H-A-S model provides containers for capturing the relevant aspects of each case relevant to redesign reasoning. Consequently, the *HMMinfo casestudies* contains cases that instantiate the particular features of the H-A-S model. Figure 7.15 illustrates the flexibility that the H-A-S model affords.

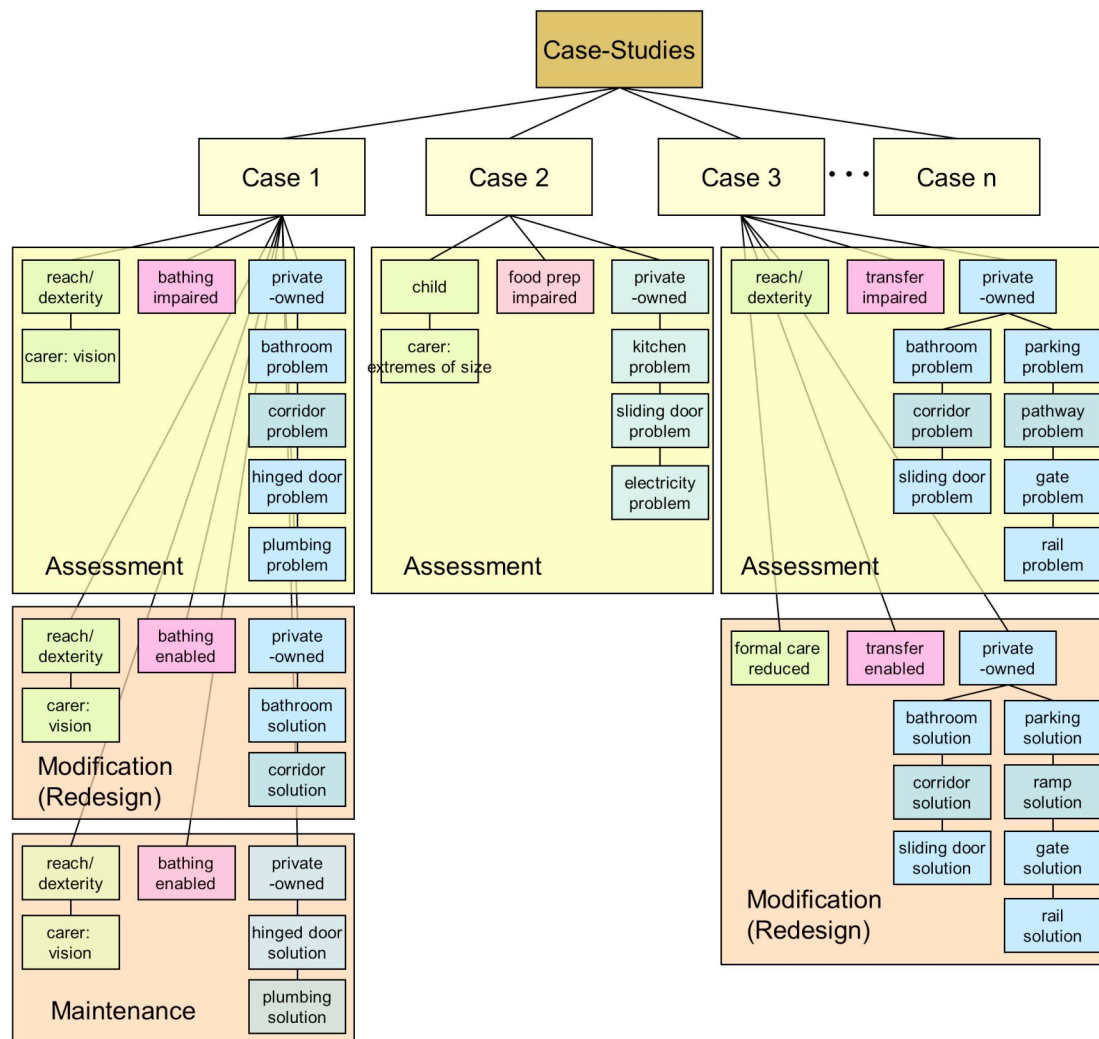


Figure 7.15: Example of variance across case instances stored in the DBMS using the Human-Activity-Space model.

As can be seen in Figure 7.15., the colours within the case type containers illustrate the H-A-S component descriptors. For example, the pale green boxes are human components, pink boxes are the activity components while pale blue boxes are the spatial components. Case types are divided into two types; assessment (lemon) and intervention i.e. modification and maintenance (apricot).

An feature alluded to in chapter two and three concerned the necessity for incorporation of multimedia data in capturing building object descriptions particularly those of a spatial nature. Within the H-A-S model housing redesign prototype multimedia data was restricted to floor plans, sketch drawings, side elevations, digital video and digital photos relevant to the home and the spaces it contained. Capturing graphics of humans and activity performance has the potential to breach privacy and confidentiality legislation and requires written informed consent. The prototype CBR because it is constructed for capturing and reasoning with *HMMInfo casestudies* online has been constructed so as to preserve privacy of Home Modification and Maintenance clients. Consequently, no personally identifying features such as the name, address or identifiable images of care recipients, carers or any other humans sharing the same spaces are stored within the database of the prototype. However, inclusion of the spatial multimedia data required modification of database storage and views (Ullman & Widom, 2002).

7.4.8 Scope and limitations of data organisation

In creating the HMMInfo casestudies prototype DBMS there are also a number of areas that are not addressed but which would make such a casebase more valuable. For instance, an ideal database system might contain a grid system of reference for spaces being reasoned about so as to allow calculations of circulation space. Ideally this would be directly linked to a computer aided drafting (CAD) system so graphic views could be dynamically created for the user. However, currently poor portability of CAD formats and software limitations in combination with lack of access to CAD skills amongst end users and absence of any CAD standardisation across the Home Modification and Maintenance sector make this option infeasible.

Additionally the International Classification of Function (ICF) data are in reality numerical codes used to identify impairment, activity and participation features of a particular person with a disability. However, for the purpose of this prototype actual values are utilized not numerical codes. Without access to a code book codes are meaningless to users and reduce transparency while increasing the complexity of computation required.

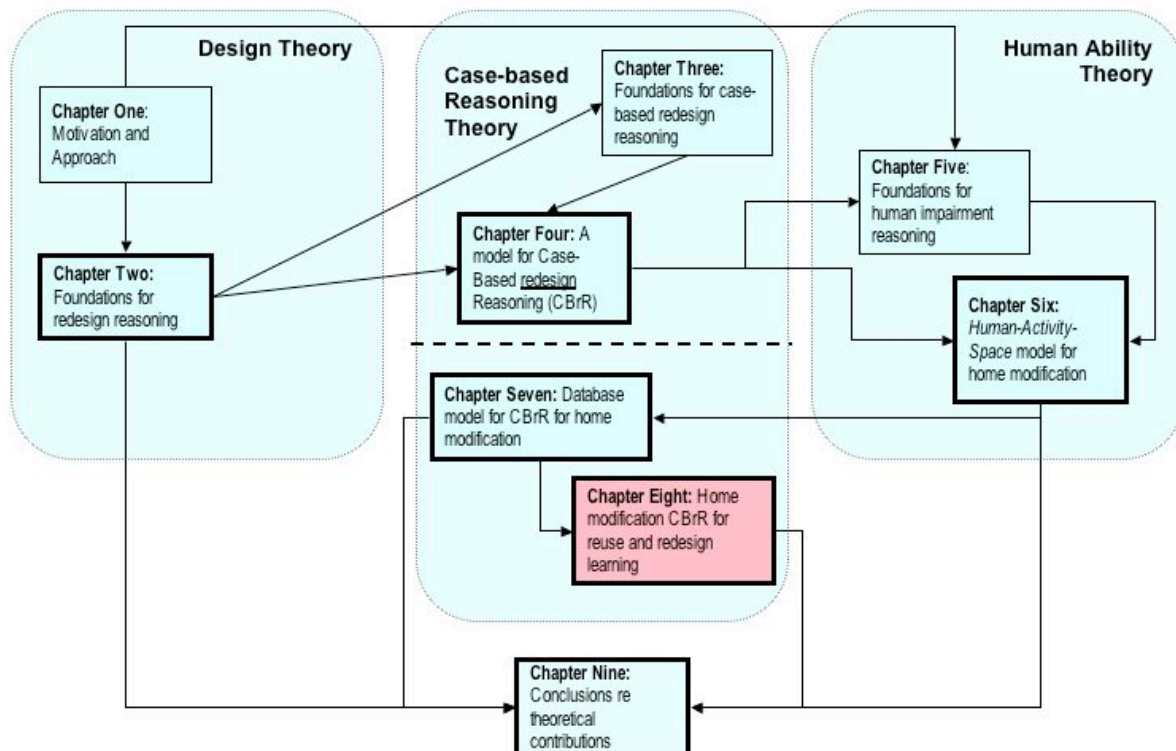
7.5 Reflexive Summary

This chapter described the rationale and process used in the construction of a DBMS designed specifically to take the Human-Activity-Space model and integrate it into a relational database specification. The DBMS has to deal with the knowledge domain contained in HMM housing redesign cases. The stages utilised in prototype development and computational formalisation of the ‘HMMinfo casestudies’ prototype was described. The specifics required of the real-world domain of HMM redesign were outlined, and implications of differences between this and the more general case representation provided by the Human-Activity-Space model were described.

Specific contributions within this chapter were:

- ▶ the presentation and rationale for the computational formalisation of the HMM housing case-type representation knowledge components. This involved further extending the Human-Activity-Space model previously presented to meet the HMMinfo casestudies prototype requirements;
- ▶ the rationale for selection of computational technologies, and choice of DBMS, in this case Microsoft ‘Access’ which determined the syntax for the development of formal base tables, data inserts and views;
- ▶ the development and presentation of a DBMS model. This resulted in a total of 44 tables which very closely mapped the models previously detailed (i.e. the CBrR model presented in chapter four and the Human-Activity-Space presented in chapter seven); and
- ▶ the demonstration of how the relationships between entities are represented within the HMMinfo Casestudies DBMS model.

8



Home modification CBrR for reuse and redesign learning

Chapter 8: Home modification CBrR for reuse and redesign learning

8.1 Introduction

In chapter two, a task model for redesign was presented. Chapter four then applied this same model to map specific redesign reasoning tasks. Chapters five and six then developed the Human-Activity-Space model to capture disability redesign knowledge. Chapter seven extended the Human-Activity-Space model to housing redesign and laid out the basics of the computational framework underpinning the implementation of the *HMMInfo casestudies* prototype. This chapter sets out to explore whether the Human-Activity-Space database management system can be usefully applied to home modification practice online. To demonstrate the functionality of these theoretical underpinnings the web pages from an online housing redesign session are used to illustrate how the *HMMInfo casestudies* operates.

8.2 Chapter Structure

First, this chapter presents the implementation of a web-based CBrR system, the ‘HMMInfo casestudies’ prototype. The prototype was designed to support human impairment related housing redesign queries using the integrated approach outlined in previous chapters. Web specific design structures, case-acquisition and navigation structures relevant to a web-based implementation are described. Second, this chapter demonstrates the terminological ontology implementation by provision of examples that demonstrate the performance of the Human-Activity-Space model operating via an online computational environment.

Third, the performance of the *HMMInfo casestudies* is evaluated by documentation of a redesign session. Actual web-snap shots illustrate case representation, case-acquisition and facilitate exploration of issues associated with navigation and reuse. Fourth, WebStats and user feedback about using the *HMMInfo casestudies* prototype to browse and submit home modification cases is presented. Finally, comment is made on how case-types and case-study features facilitate reasoning including problem sensing and problem validation.

8.3 Integration of human impairment knowledge and disability reasoning

The framework for implementation outlined in chapter eight stemming from the Human-Activity-Space housing redesign data model allows a CBrR operating in housing redesign to store case instances. In chapter seven the computational implementation framework used case-type partitioning to catch the traditional differentiation between assessment (problem

sensing) and modification or maintenance (problem validation) reasoning. Thus the prototype CBrR system developed captures two of the most crucial human impairment reasoning tasks.

The case-type partitioning however has the additional advantage of preserving the linkages between case types, which was alluded to in the discussion of motivation in chapter one. Figure 8.1 illustrates how the Human-Activity-Space model, as extended to housing redesign assists in integration of the human impairment methodology (H-A-S ontology) and computational technology (CBrR) model.

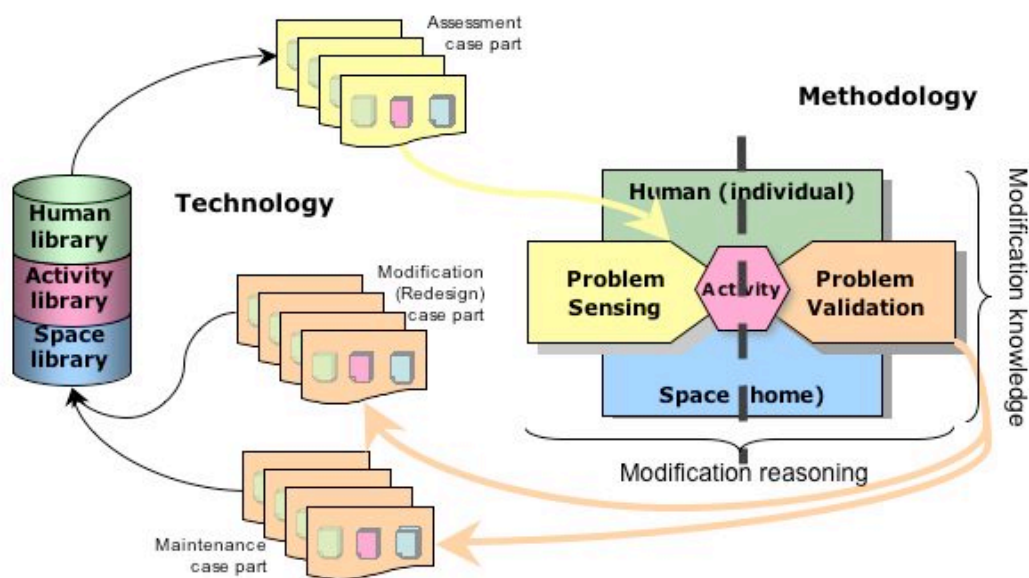


Figure 8.1: Overview of the Home Modification and Maintenance Case-study prototype's methodology and technology

The lack of strong domain theory means that human impairment reasoning always involves some degree of uncertainty. Consequently, it relies on individual clinical judgment, not on application of established rules. Human impairment reasoning draws on human, activity and spatial domain knowledge unlike rehabilitation reasoning which concerns knowledge of the domain of human ability or architectural design reasoning which is typically restricted to environmental or spatial data. As we saw in chapter five, human impairment reasoning focuses on adapting or changing environmental attributes in order to maximise human ability to perform activities with greater independence, comfort and safety and has direct and indirect health benefits. The application of CBrR technology facilitates case-based reusability and redesign learning. Moreover, it provides a novel means of resolving a real world knowledge gap.

Reasoning about redesign for persons with human impairment can be viewed as a specialised subset of redesign reasoning. As such, it inherits many of the same technological strategies as

other DBMS and web-based approaches. Figure 8.2 illustrates the two most significant CBR tasks i.e. recall and reuse. *Recall* is enabled by the user executing commands at the keyboard in regard to accessing case indexes, selecting them and ranking retrieved cases for fit to the redesign task. *Reuse*, on the other hand, allows the user to submit a case, reuse an existing case or case parts and edit or adapt them to fit the new intervention situation. Nevertheless the HMMinfo casestudies prototype differs from more standard approaches in that it stems from both a new model of CBrR and the Human-Activity-Space model. Incorporation of these theoretical underpinnings provides flexibility in the manner that domain knowledge is acquired, stored, browsed and reused while enabling redesign learning.

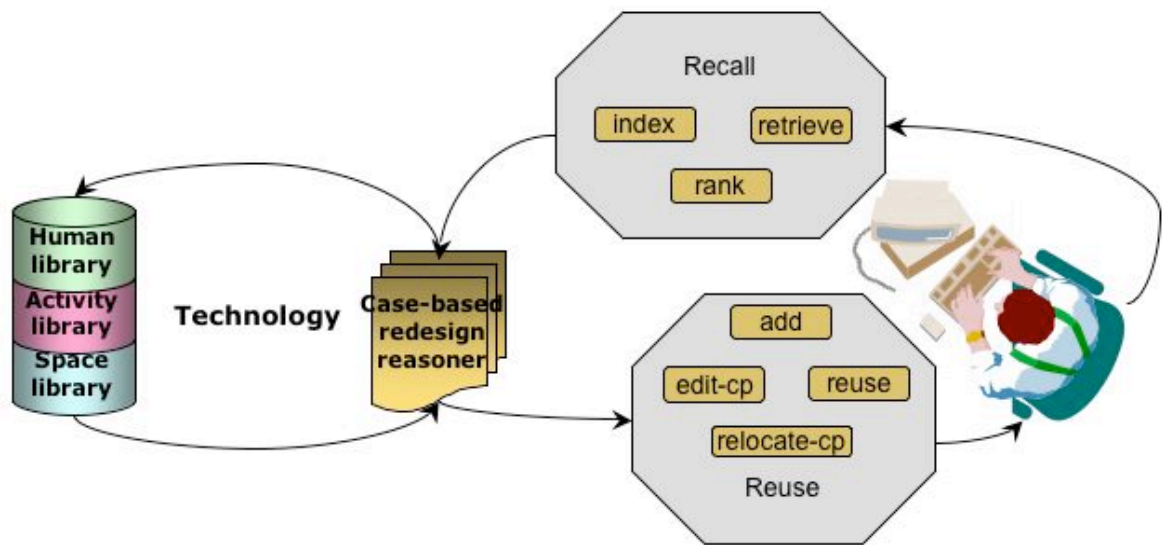


Figure 8.2: CBrR technology

To better understand how the methodology and technology are integrated in practice within the HMMinfo casestudies prototype, it is helpful to examine how a typical modification case might be acquired or added to the case-library and what this means for reasoning and reuse. A fairly typical home modification scenario in freetext form might look something like that given in the text box. This somewhat vague description is converted into very specific information as details are entered into the online case acquisition forms based on the H-A-S ontology and are thus acquired and stored in the casestudies database for later reuse. The DBMS acquisition and reuse process is outlined as follows in the case acquisition example.

Mrs. McLean, an older lady with multiple sclerosis was referred to the home modification service for an assessment following a fall in her bathroom. The occupational therapist from the local Area Health Service in collaboration with the builder from the home modification service drew up some plans for potential modifications to Mrs. McLean's granny-flat. Data from this assessment was entered as an assessment case. Following approval by Mrs. McLean, the modification interventions were carried out. The modification work took two weeks. A number of structural features required attention during works that were unanticipated and some of the products specified in the assessment were unobtainable at the time of construction. Besides, Mrs. McLean was concerned about finances so decided to focus on the bathroom.

In conducting the assessment or problem sensing case-type part, an experienced occupational therapist should have been able to quickly identify a set of human performance issues likely to be of significance in finding a solution for Mrs. McLean's situation. For example, an expert home modification reasoner would be able to link the fall Mrs. McLean had sustained to the distance to and transfer obstacles evident within Mrs. McLean's home. This sort of knowledge is then translated to a potential home redesign solution hypothesis.

For example, it may have occurred to an experienced home modification practitioner that Mrs. McLean might benefit from level access to the bathroom as this will likely improve her ability to transfer independently and reduce the chance of secondary injuries. The observed problems resulting from Mrs. McLean's mobility impairments and her current equipment, habits and activity patterns within her existing home spaces are linked to potential solutions and stored as an assessment case. However the intervention solutions at this stage are hypothetical only and may require re-evaluation or may never be acted on for a variety of reasons.

When reasoning about assessment, a human problem solver is trying to create a frame for a new problem situation they are exploring. For instance, in order to respond to the referral and to determine whether Mrs. McLean can remain in her current home safely, an experienced practitioner would pay attention to factors which related to their prior experience or existing knowledge and which they considered important. The overall objective being to determine Mrs. McLean's needs and wants as accurately and efficiently as possible.

Thus in stage one, *assessment* (problem sensing or noticing), attention is being paid to the new requirement and reasoning is based around that. For instance, if a redesigner wanted to change an environmental or spatial artefact, such as Mrs. McLean's bathroom, they might choose to explore any previous cases that matched either Mrs. McLean's impairments, activity restrictions or similar bathroom configurations in order to gain insight about significant relationships likely to be of relevance to Mrs. McLean.

The original assessment referral for Mrs. McLean would have contained cues that would have framed a case-based redesign query session and which would have assisted an exploration of certain attribute relationships. For example, what aspects of human ability might have caused Mrs. McLean to fall in the bathroom, what activities was she undertaking and how was she accomplishing the tasks that comprised the activities, what was the relationship between Mrs. McLean's ability and the spatial attributes provided within her bathroom that may have contributed to her fall or that will impact on her potential to remain at home, etc.?

If Mrs. McLean's assessment is already stored within our CBrR's case library as an 'assessment' case-type, the task of acquiring the problem validation or actual 'modification' case-type data becomes much easier, as we can *reuse* the assessment case. Reuse allows the user to only change the particular fields that are different or have varied over time, rather than having to enter data about the case from scratch.

Accessing Mrs. McLean's assessment case allows the user to edit the case contents, including the actual intervention details, plans, photos and costs. Details about Mrs. McLean and her family can, for the better part, be reused without a great deal of modification as there has been little change in the time period between applying for funding and having the work completed. Obviously the more degenerative the health condition and impairments are and/or the longer the time interval the more likely changes will need to be made. Reusing the assessment case has the dual advantage of linking the assessment and modification case-types and reducing the amount of time and effort in uploading the new modification solutions to the case-library.

8.4 Home Modification and Maintenance Housing Casestudies System

In order to reuse, browse or submit a case, first the user has to locate the URL for the HMMinfo casestudies website. They can do this either by going to the HMMinfo clearinghouse home page (see Figure 8.3) at <http://www.arch.usyd.edu.au/hmminfo.html> or by entering the casestudies section URL directly into their web browser http://plan.arch.usyd.edu.au/hmm/hmm_web/casestudy/start/index.cfm. If the user enters via the Home Modification and Maintenance Information clearinghouse homepage they would need to locate the *casestudies* link, which is the second to the left of the minor content areas within the website.

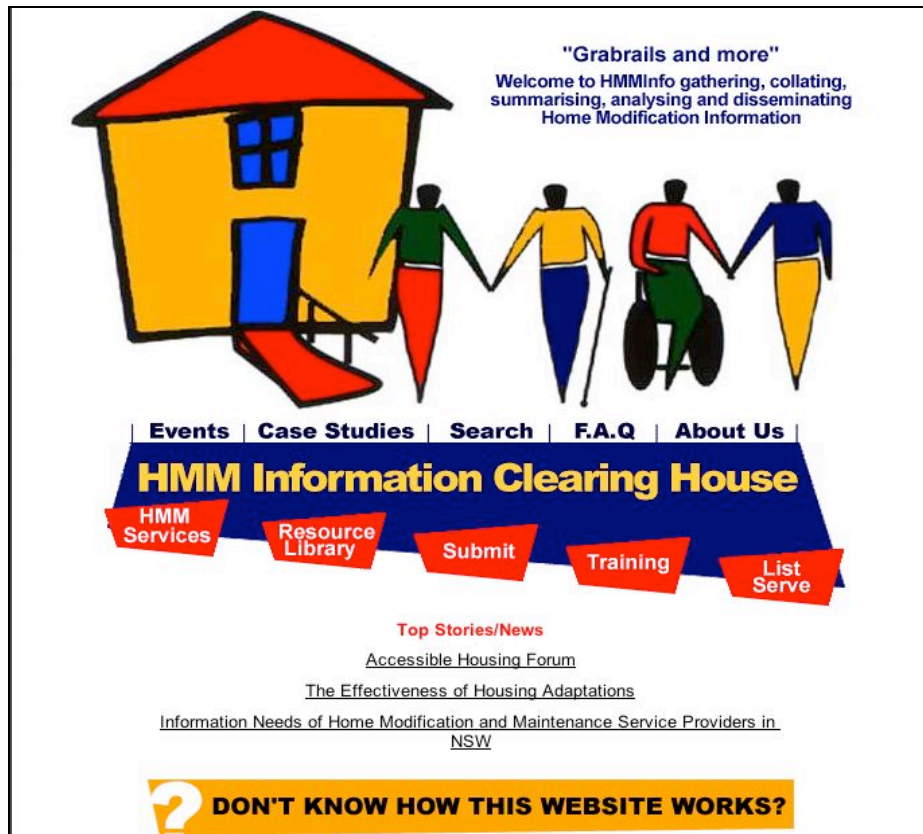


Figure 8.3: Link to the Case Studies area from the Home Modification and Maintenance Information Clearinghouse website homepage

When the user arrives at the casestudies section they can either login as a guest or as a user. Login enables the case-library to recognise users and means that data about the user is only requested once, but is available to the user for editing and to the database for linking to cases submitted or reused by that user automatically. The system automatically generates a simple password but the user can edit this to facilitate cognitive recall once they have completed their initial login and are redirected to the casestudies main page. Data is collected about professional background, years of experience and contact details. These details are immediately important in terms of providing the case creator with copyright for solutions and could be useful to other users in searching and reusing cases. Once a user has completed login they are automatically redirected to the casestudies section main page where they can select the CBrR activity they would like to complete.

It is probably helpful at this point to illustrate how the casestudies section is organised and how the web pages were designed to relate to each other and the backend database or case library. Figure 8.4 illustrates the web page sequence experienced by a user visiting the online HMMInfo casestudies prototype. As is evident depending on the selections made at the casestudies main page, the user will be presented with a number of form-based options that guide the user through the decision-making process one step at a time. This is possible

because the web pages are generated dynamically so, if a user fails to proceed as expected or attempts to proceed without making a selection or entering information, they will receive a prompt or error pop-up giving them more assistance about the action that what was anticipated but not executed.

Qualitative feedback from in-depth interviews with just under a third of the Home Modification and Maintenance service providers within NSW clearly identified that many users' were unfamiliar with the Web and wanted a computational environment that was familiar, non-threatening and generally tolerant of error. (Bridge & Martindale, 2003). Thus ease of use was an important design requirement.

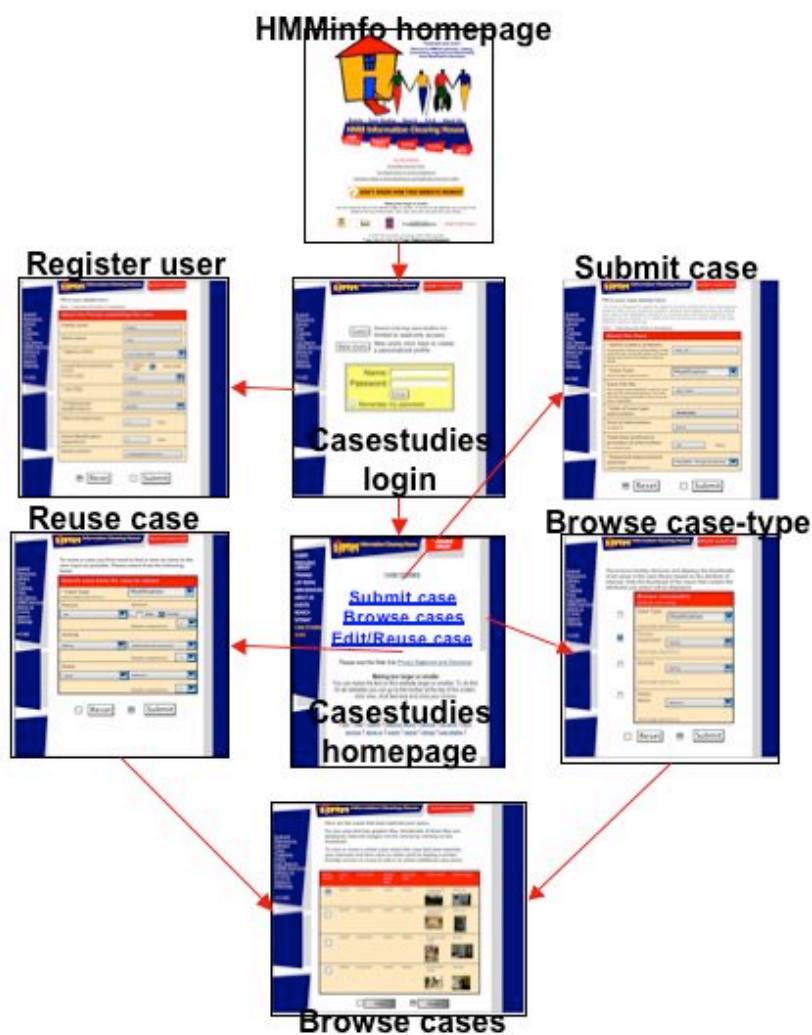


Figure 8.4: Sequence of relational links within the HMMinfo Casestudies Prototype illustrating the relationship of web pages to CBR tasks

Figure 8.5 illustrates how the data elements evident in the forms used for case submission; case selection and login are employed to manage storage and retrieval of cases. This alternative way of looking at the organisation of web pages also serves to illustrate how all

case related data is partitioned into Human-Activity-Space attributes and how this information is stored in an integrated fashion within cases being browsed or reused but is stored in a segregated fashion within the case-library backend databases.

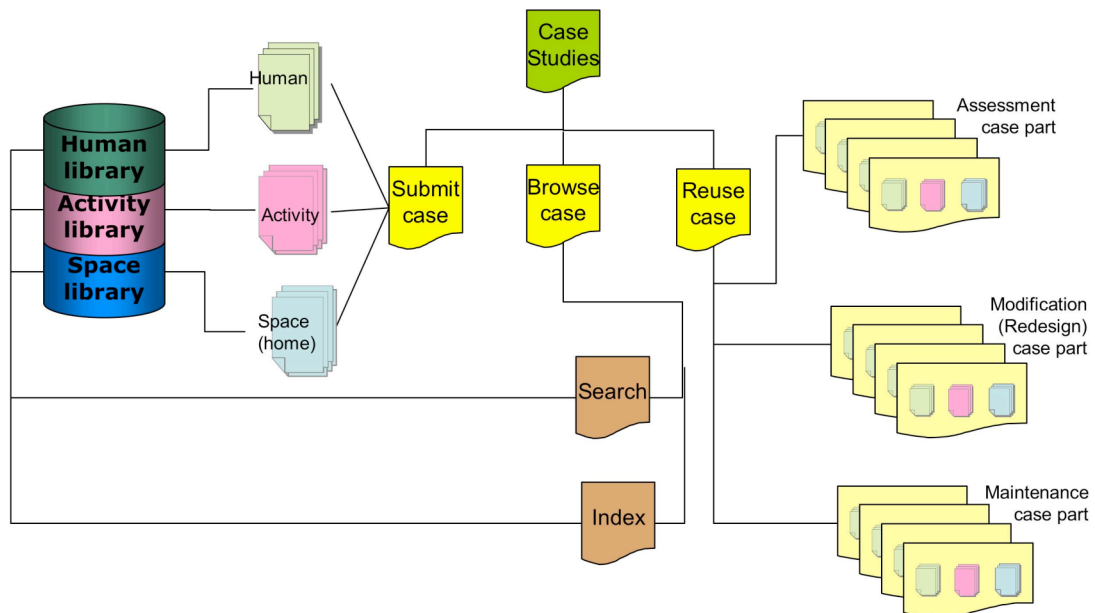


Figure 8.5: Online queries from HTML pages dynamically index and retrieve data in the Home Modification and Maintenance Case-study Prototype

8.4.1 Selecting, browsing, acquiring and reusing case data: Model driven stages

Now that our user has completed login they can choose to enter Mrs. McLean’s modification case data either as a new case or by reusing a previous case. Given that Mrs. McLean’s assessment case is already stored in our case library, choosing to reuse the assessment case data can speed up data entry. To locate the assessment case from the case library first the user has to query the database. In the HMMInfo casestudies prototype this is a staged process using a browsing model for case based exploration. A direct search using pattern matching on terms directly associated with but unique to a particular case such as case file number would retrieve a case more directly but is not yet implemented.

8.4.1.1 Selecting and ranking cases of interest from within the ‘HMMInfo casestudies’ library

As discussed in chapter four, browsing assists users’ in the process of information discovery by helping them to identify searchable text (terms) and by assisting users’ to develop conceptual maps of case data contents. Topic level browsing is the norm, this is where document sources are categorised or linked at a logical level according to a particular topic (Hoppenbrouwers, 1998). In our CBR prototype the Human-Activity-Space model provides an organisational framework for accessing stored cases from the case library. Figure 8.6

illustrates the four primary categories for browsing. For instance, ‘Case Type’ includes assessment, modification and maintenance types. While ‘Person (human) Impairment’ includes impairment labels (e.g., older, cognitive, vision, hearing etc.). The category ‘Activity Impaired’ includes activity labels (e.g., bathing, toileting, transferring etc.) and ‘Home Type’ includes ownership labels (e.g., owner-occupied, rental etc.). The first stage of hierarchical browsing implemented within the prototype is of necessity general and the Human-Activity-Space model provides the primary case-data indexing structure.

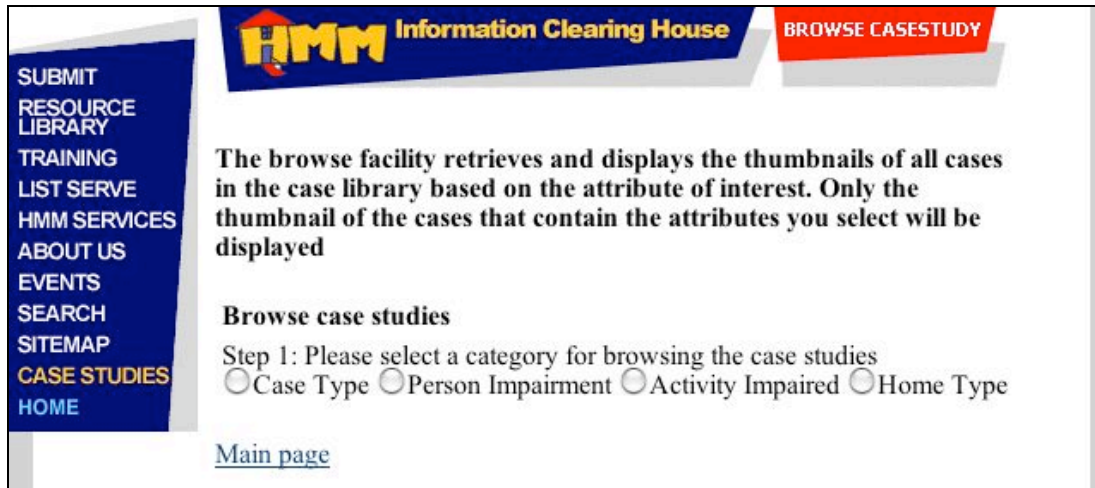


Figure 8.6: Browsing cases: Step 1-Model based structured indexing

Once the user selects a primary category of interest, they then move to stage two. Figure 8.7 illustrates how, having selected case type in stage one, a drop down list to select from is then automatically generated. In this manner the user moves down the category levels in a hierarchical fashion.

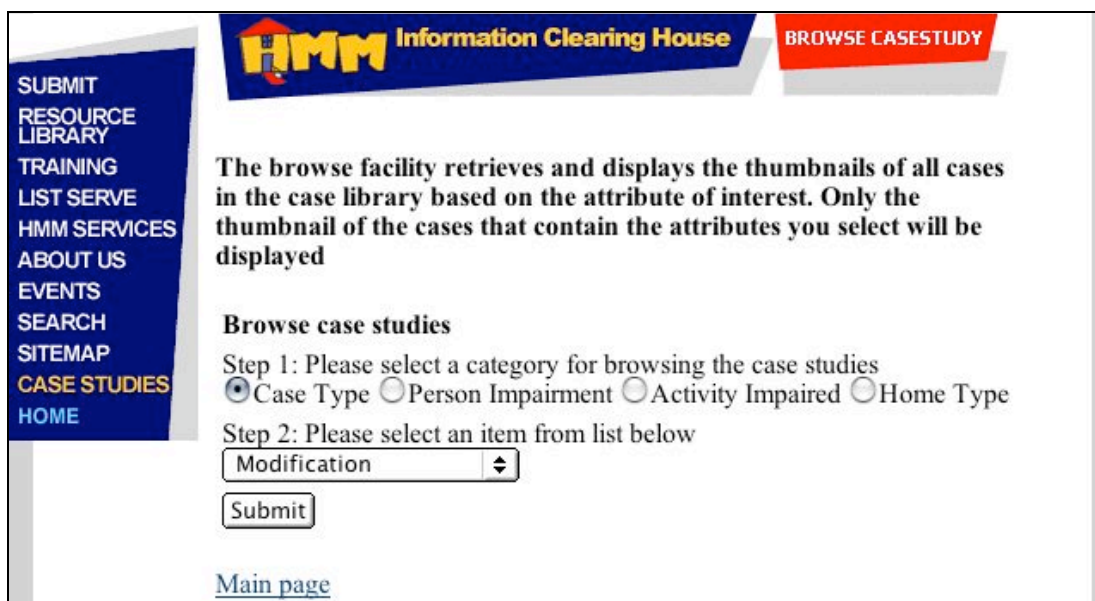


Figure 8.7: Browsing cases: Step 2 - User based ranking based on attribute of interest

In our users' case the most logical method of locating Mrs. McLean's assessment case for reuse purposes requires the initial selection of 'case type' followed at the next level down by selecting 'assessment'. This two-level process is a simplified system of enabling user selection and ranking of cases based on *model based indexing*⁶ (Bhatta & Goel, 1995). The field 'case-type' has a mandatory value that is part of the case data, which is indexed when the case is acquired. The user selects an item from a range of values either via dynamic drop down menus or via clickable radio buttons. For instance, a user may locate a case using features of importance to them, such as the activity features within a case like 'bathing (or showering)' or spatial features such as 'private-owned purchasing'.

8.4.1.2 Browsing case data to confirm reusability

The HMMinfo casestudies prototype user could locate Mrs. McLean's original assessment case file in a number of ways, the most obvious method being the selection of the 'assessment' case type option as seen in Figure 8.8. The query in this case is very general in other words all "assessment case-types" currently stored in the casestudies library will be returned. The user then has to scan down the cases listed until they recognise person impairment, activity impairment and home type features that match the details corresponding to Mrs. McLean. In order to preserve Mrs. McLean's privacy and confidentiality at no point will Mrs. McLean's personally identifying details, such as her real name or address or images of her or others associated with her case, be available. Further no case can be submitted without written consent from the persons involved in the case⁷.

Alternatively a user can locate a case by using attributes of the person's impairment such as 'Mobility (incomplete use of feet or legs)' as in Figure 8.9.

⁶ Search occurs following the data model (i.e. data records and indexing act to organise data in the manner prescribed by the model).

⁷ Please see appendices for human ethical clearances and client consent to submit case details to the HMMinfo Casestudies database for online display.

SUBMIT

RESOURCE LIBRARY

TRAINING

LIST SERVE

HMM SERVICES

ABOUT US

EVENTS

SEARCH






SITEMAP

CASE STUDIES

HOME

Here are the case that best matched your query.

5 record(s) found

	Case Type	Person Impairment(s)	Activity Impaired	Home type
<input type="radio"/>	Assessment	* Reach/Dexterity (incomplete use of arms/fingers and/or difficulty gripping)	* Bathing (or showering) * Housekeeping * Food preparation * Laundry * Shopping * Transportation	Private-owned/purchasing 
<input type="radio"/>	Assessment	* Energy/Stamina * Reach/Dexterity (incomplete use of arms/fingers and/or difficulty gripping) * Sensation (numbness, pain or tingling chronic or recurring)	* Bathing (or showering) * Dressing * Housekeeping * Shopping * Transportation * Stairs	Private-owned/purchasing 
<input type="radio"/>	Assessment	* Mobility (incomplete use of feet or legs) * Vision (not corrected by glasses) * Sensation (numbness, pain or tingling chronic or recurring)	* Bathing (or showering) * Shopping * Housekeeping * Food preparation * Laundry * Transportation * Stairs * Transfer	Private-owned/purchasing  
<input type="radio"/>	Assessment	* Reach/Dexterity (incomplete use of arms/fingers and/or difficulty gripping)	* Bathing (or showering) * Housekeeping	Private-owned/purchasing 

Mrs McLean's assessment case

Figure 8.8: Browsing Case Studies: Step 3 - User based selection based on Case Type retrieval (Mrs. McLean's assessment case is identifiable by the red box)





<input type="radio"/>	Assessment	<ul style="list-style-type: none"> * Mobility (incomplete use of feet or legs) * Vision (not corrected by glasses) * Sensation (numbness, pain or tingling chronic or recurring) 	<ul style="list-style-type: none"> * Bathing (or showering) * Shopping * Housekeeping * Food preparation * Laundry * Transportation * Stairs * Transfer 	Private-owned/purchasing  
<input type="radio"/>	Modification	<ul style="list-style-type: none"> * Mobility (incomplete use of feet or legs) * Vision (not corrected by glasses) * Sensation (numbness, pain or tingling chronic or recurring) 	<ul style="list-style-type: none"> * Shopping * Housekeeping * Food preparation * Laundry * Transportation * Stairs 	Private-owned/purchasing  


Figure 8.9: Browsing Case Studies: Step 3 - User based selection based on ‘Person impairment’ type retrieval

Provision of case annotations and multimedia in step three browsing facilitates comparison of features across cases, drawing on the users’ disability domain and housing knowledge. It also allows comparison of cases across all the model features facilitating selection of a case that best fits all the features of relevance.

Figure 8.10 illustrates this type of feature driven browsing in operation. The results appear similar to the assessment search for two reasons. Firstly the total cases within the case base are small in number and secondly all cases within the case-base currently contain ‘bathing’ type activities. Bathroom modifications comprise 54-29 % of all modification requests depending on disability severity (Australian Bureau of Statistics, 1998). Further the Australian Institute for Health and Welfare states that in home modification practice those living in rental properties are typically excluded resulting in a skew towards home ownership as the predominant housing type (2003).

Nevertheless, the inherent flexibility provided by incorporation of the Human-Activity-Space model within the browsing utility means a user can locate the most appropriate case based on the attribute that is of most interest to them at the current time as long as cases of that type are held within the case-base. The model also provides multiple means of accessing case library contents thus facilitating ease of use.

When selecting a particular feature, all the cases within the case library matching this feature are displayed for user based selection in the order that they have been entered into the case-base. Meaning that the oldest cases are displayed first and the most recently acquired cases matching the feature of interest last.



BROWSE CASESTUDY

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 HMM SERVICES
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 SITEMAP
 CASE STUDIES
 HOME

Here are the case that best matched your query.

5 record(s) found




	Case Type	Person Impairment(s)	Activity Impaired	Home type
<input type="radio"/>	Assessment	* Reach/ Dexterity (incomplete use of arms/fingers and/or difficulty gripping)	* Bathing (or showering) * Housekeeping * Food preparation * Laundry * Shopping * Transportation	Private-owned/purchasing  *
<input type="radio"/>	Assessment	* Energy/ Stamina * Reach/ Dexterity (incomplete use of arms/fingers and/or difficulty gripping) * Sensation (numbness, pain or tingling chronic or recurring)	* Bathing (or showering) * Dressing * Housekeeping * Shopping * Transportation * Stairs	Private-owned/purchasing  *
<input type="radio"/>	Assessment	* Mobility (incomplete use of feet or legs) * Vision (not corrected by glasses) * Sensation (numbness, pain or tingling chronic or recurring)	* Bathing (or showering) * Shopping * Housekeeping * Food preparation * Laundry * Transportation * Stairs * Transfer	Private-owned/purchasing  *  *

Figure 8.10: Browsing Case Studies: Step 3 - User based selection based on ‘Activity’ or ‘Home’ Type retrieval

Once the user has located the case of most interest the user can choose to either browse or reuse it. If a user selects the browse option, the highlighted case is retrieved and displayed as a set of static HTML pages divided into sections corresponding to the Human-Activity-Space model. The browse option differs from the reuse option in that the reuse pages are editable. In our case, where a user is attempting to locate Mrs. McLean’s assessment case the user might choose to browse or examine the selected case pages first in order to ensure that it is in reality the case that was being sought or that the match is near enough. The user can scroll through

the entire case quite quickly to scan case contents or they can click on links or thumbnails of embedded multimedia for more detail as needed. Figure 8.11 illustrates Mrs. McLean’s case details, including fields and their values associated with the case type (i.e. assessment), the cost, time and problems associated. This basic case data is displayed at the top of the HTML page.

The screenshot shows the HMM Information Clearing House website. On the left is a blue navigation menu with links: SUBMIT, RESOURCE LIBRARY, TRAINING, LIST SERVE, HMM SERVICES, ABOUT US, EVENTS, SEARCH, SITEMAP, CASE STUDIES, and HOME. The main header features the HMM logo and the text 'Information Clearing House' next to a red 'BROWSE CASESTUDY' button. Below the header, the 'Case Details' section is displayed in a table format:

Case Details	
HACC Letters of Name:	claem
Case Type:	Assessment
Case File No:	P95/00538/01
Date of case type intervention :	14 February 1995
Cost of intervention (in whole \$):	\$600.00
Total time involved in provision of intervention (to nearest hour):	7 hours
* Current problem(s):	Independence,Safety
* Expected improvement outcome:	Independence,Safety

Figure 8.11: Browsing HMMinfo casestudies for ‘Case’ data: Case contents are displayed as HTML based on the Human-Activity-Space model

Contents can be viewed by scrolled down and contents are ordered according to the Human-Activity-Space model. As Figure 8.12 illustrates, the person or (human) case data is presented next.

Person Details

Number of Persons associated: 2
 Person 1 [\[View details\]](#)
 Person 2 [\[View details\]](#)

Person 1 details

Type: CareRecipient
Sex: female
Age (to closest year): 64
Receipt of Formal care services: - Home help
Living arrangements: Lives with family
Government pension/benefit: Aged Pension
Primary Medical Diagnosis: Multiple sclerosis
Medical prognosis: Degenerative
Height: 2 mm
Weight: 52 kilograms
Limb segment length: In proportion
Limb contractures: None
Spinal curvature: Scoliosis

Person particulars: * frail lady of slight build * lower left leg weakest, * lower limb drag when ambulant * 2 falls in last month * Home care fortnightly (clean bathroom, bedroom and vacuum)

Impairment details:

1. Mobility (incomplete use of feet or legs) - Moderate problem
2. Vision (not corrected by glasses) - Moderate problem
3. Sensation (numbness, pain or tingling chronic or recurring) - Mild problem

Figure 8.12: Browsing HMMInfo casestudies for ‘Human’ data: Case contents are displayed as HTML based on the Human-Activity-Space model

Scrolling down the web page examining the same case details, after scanning the human data, the activity related data follows as illustrated in Figure 8.13.

Activity Details	
Activities impaired:	<ol style="list-style-type: none"> 1. Bathing (or showering) - Physical assistance required 2. Shopping - Dependent 3. Housekeeping - Dependent 4. Food preparation - Dependent 5. Laundry - Dependent 6. Transportation - Dependent 7. Stairs - Physical assistance required 8. Transfer - Physical assistance required
Equipment provided/available:	Wooden ramp at front, Electric scooter (Shoprider), adjustable walking frame (KA 350)
Activities enabled:	Bowel, Bladder, Grooming, Toilet use, Feeding, Dressing, Telephone
Activity Particulars:	* Ambulant at present using walker, at times unsteady. * Has difficulty climbing stairs and does not appear safe despite rails both sides. * Independent in personal care though exhausts easily. * Presently using a bath

Figure 8.13: Browsing HMMInfo casestudies for ‘Activity’ data: Case contents are displayed as HTML based on the Human-Activity-Space model

The next area to be displayed of the same assessment case is the data pertaining to the home. Details about the home and spaces and links of relevance are illustrated in Figure 8.14. Within the home page are any embedded multimedia images relating to the assessment of the home in general.

Home Details

Area of residence : New South Wales

Local Government Area (LGA) Within NSW
Parramatta

Postcode: 2175
(If in Australia)

Accommodation setting : Private-owned/purchasing

Number of spaces associated: 3

Space 1 [\[View details\]](#)

Space 2 [\[View details\]](#)


Space 3 [\[View details\]](#)


Number of Links associated: 1

Link 1 [\[View details\]](#)

Home Particulars: Granny flat composed of single large bedroom with external bathroom and rear access connected to main homestead (brick single storey bungalow) by hall passageway. Sloping site.

Home Images:

1. Photo 

2. Plan drawing 

[End session](#) [Main menu](#) [Browse/Reuse another case](#)

Figure 8.14: Browsing HMMinfo casestudies for ‘Home’ data: Case contents are displayed as HTML based on Human-Activity-Space model

The user can then click on the space or link pop-ups (separate HTML pages which are embedded into the case). The pop-ups allow the user to view more detail about the proposed modifications and associated problems with the existing arrangements. Space pop-ups contain data about physical rooms (i.e. those bounded by walls and ceiling) and virtual spaces (i.e. those unbounded by walls and ceiling). This allows representation of the full range of relevant home spaces including bathrooms, bedrooms on road parking, patio and garden spaces etc. Link pop-ups, on the other hand, contain information about means of connecting spaces (i.e. corridors, stairs, lifts etc.). Only those spaces or links of relevance to the particular case-type are stored for browsing and reuse. The space pop-up for Mrs. McLean’s bathroom is illustrated in Figure 8.15. As can be seen this contains additional details about the actual

spatial dimensions and features and contains textual and multimedia data with additional detail. The detail about the access points to the space or link and the services associated with the space and link.

About the Space	
Space Type :	Bathroom general
Width:	1300 mm
Length:	3130 mm
Height:	-
* Shape :	Rectangular
Wall Particulars:	combination of double brick cavity wall partition and fibro walls with with tile finish.
Floor Particulars:	Concrete slab with high gloss 20 mm floor tile.
Ceiling Particulars:	compressed fibro false ceiling with cornice containing ceiling fan and lighting.
Intervention Particulars:	Small external shower and toilet space originally designed to serve outdoor pool area
<hr/>	
* Services :	Electricity,Lighting
* Access Points :	Hinged door
Access Points description :	Hollow core inward opening door with clear open width of 650 mm.
<hr/>	
Space Images:	
1) Image Type :	 <p>Plan drawing</p>
2) Image Type :	 <p>Photo</p>

Figure 8.15: Browsing HMMInfo casestudies for ‘Space’ data: Case contents are displayed as linked HTML pop-ups based on ‘Accessible Space’ model

Our user now having browsed Mrs. McLean’s assessment case has now confirmed that this case is close enough and that reuse will be the most effective way to add the new modification case to the case-library.

8.4.1.3 Case acquisition and reuse functions

The first stage of adding our new modification case to the case library involves provision of general case information. This first stage of case acquisition is illustrated in Figure 8.16. In the general case form, data is gathered about the case-type, the date of intervention, the cost of intervention and the time spent in intervention. If our user was to reuse Mrs. McLean’s

original assessment case, all these fields would need to be modified to accommodate our new modification case.

However fields such as the case file number are traditionally allocated to a particular client or person so would typically remain unchanged. Data like case file number would also allow the user to use this data to cross-reference paper based records and would enable search for a particular case file number across the case library. This may be important as normal case handlers like name and address have been either encoded or removed to preserve client or care service recipient's privacy. A case submitter or service provider might want to use the case-file number to delete, reuse or update cases associated with a particular person.

The screenshot shows a web interface for 'Information Clearing House'. On the left is a vertical navigation menu with links: SUBMIT, RESOURCE LIBRARY, TRAINING, LIST SERVE, HMM SERVICES, ABOUT US, EVENTS, SEARCH, SITEMAP, CASE STUDIES (highlighted), and HOME. The main header features the HMM logo and a 'REUSE CASESTUDY' button. Below the header, the text reads: 'Fill in your case details here: This form is designed to assist the capture of home modification and maintenance cases so they can be reused for problem sensing and problem solving. By adding your case to the database, innovative or unusual case information problems and solutions can be shared. It is hoped that this sharing may assist better and more effective practice outcomes.' A note states: 'Note: * indicates this field is mandatory'. The form section is titled 'About the Case (Step 1 of 4)' and contains the following fields: '* HACC Letters of Name:' with a text input containing 'claem'; '* Case Type:' with a dropdown menu set to 'Modification'; and 'Case File No:' with a text input containing 'P95/00538/01'. Explanatory text for the Case File No field reads: 'The unique case identifier used by your agency for record purposes. You can use this to find and edit a'.

Figure 8.16: Case acquisition: Step 1-General case information

When the user has completed step one they click on the 'next' button to proceed to the second step. As illustrated in Figure 8.17 this form collects data about the persons involved. This aspect has been designed to accommodate as many persons as will be affected by housing modifications as needed. This may be one or a number of persons being either care recipients or carers. As in our assessment case, the care recipient co-habits with her family and her daughter is the primary care provider. However as is evident formal care in the form of homecare is also provided.

The requirements of carers, not just clients, will determine the suitability of the interventions provided. For instance, as in this modification case, homecare provision is dependent on a work environment that is safe for the care provider. The activities of homecare will be impacted on by intervention product choices. Say, for instance, that non-slip tiles were installed. The cleaning required should minimise reaching and bending so that neither the client nor the carer was placed in a situation of risk. In this sense, data about maintenance impacts redesign reasoning. In a group home or hostel facility it is also not uncommon to have multiple care recipients. Accommodating all care recipients so that none are disadvantaged by modification interventions is also critical. This flexibility allows the capturing of data about one or many persons impacted by the interventions as relevant to each case instance.

HMM Information Clearing House REUSE CASESTUDY

SUBMIT
RESOURCE LIBRARY
TRAINING LIST SERVE
HMM SERVICES
ABOUT US
EVENTS
SEARCH
SITEMAP
CASE STUDIES
HOME

Fill in your case details here:
 Note: * indicates this field is mandatory

Number of Persons associated so far: 2
 Person 1 (CareRecipient) [\[Edit details\]](#) [\[Delete\]](#)
 Person 2 (Carer) [\[Edit details\]](#) [\[Delete\]](#)

[Add More Person](#)

About the Person (Step 2 of 4)

Person 1 details

* **Type:** Care Recipient Carer
 * **Sex:** Male Female
 * **Age (to closest year):**
 * **Receipt of Formal care services:**
 Community nursing
 Community-based respite care (mostly day care)
 Education and/or training information and advocacy services
 Home help
 Meals on wheels and day centre-based meals

(Hold 'Control' key (PC) or 'Command' key (Mac) while clicking to select multi)

* **Living arrangements:**
 * **Government pension/**

Figure 8.17: Case acquisition: Step 2-General person (human) data

The third step is the collection of data for the primary client (either carer or care recipient whichever is the primary client) about the activities that are impaired, enabled, the equipment provided and the habits or preferred patterns of activity performance (activity particulars).

Collecting information about the activities enabled not just the severity of the activity impairment is also important. Figure 8.18 illustrates the acquisition of activity relevant data. Activity relevant data enables redesign learning such that activity outcomes changes are either clearly evident or not when assessment and modification cases are linked such as when reusing the assessment case as a basis for modification data entry. In this manner the activity data provides an important means of evaluating redesign case outcomes not just in terms of expected outcomes (assessment) but actual outcomes values as determined by post-occupancy evaluation (modification).

HMM Information Clearing House REUSE CASESTUDY

SUBMIT
RESOURCE LIBRARY
TRAINING
LIST SERVE
HMM SERVICES
ABOUT US
EVENTS
SEARCH
SITMAP
CASE STUDIES
HOME

Fill in your case details here:

Note: * indicates this field is mandatory

About the Activity (Step 3 of 4)

Activity impaired :

Severity of Impairment :

*** Activities impaired:**

- 1. Shopping - Dependent
- 2. Housekeeping - Dependent
- 3. Food preparation - Dependent
- 4. Laundry - Dependent
- 5. Transportation - Dependent
- 6. Stairs - Physical assistance required

Equipment provided/available:

*** Activities enabled:**

(Hold 'Control' key (PC) or 'Command' key (Mac) while clicking to select multiple items)

Particulars:

Figure 8.18: Case acquisition: Step 3 - General activity data

The fourth step involves the acquisition of information about the home. As is evident in Figure 8.19, fields such as area of residence and postcode allow comparison of cases geographically but fields such as accommodation setting enable accommodation type comparisons. For instance, large-scale modifications are much less common in rental

accommodation and later comparison of cases on accommodation type might yield interesting data about the environmental setting where particular interventions are most common. This form also captures all the connected space and link information and enables the user to add multimedia data as relevant. Multimedia data in the form of photos, plans, sketches and video are important in capturing more detail concisely relevant to case outcomes. As indicated earlier the multimedia case acquisition feature facilitates the uploading of digital media files that are attached to case data and embedded in browsing and case selection views. All graphics are automatically stored as thumbnails and full-scale pictures can be viewed by clicking on the thumbnail.

HMM Information Clearing House REUSE CASESTUDY

SUBMIT
RESOURCE LIBRARY
TRAINING
LIST SERVE
HMM SERVICES
ABOUT US
EVENTS
SEARCH
SITEMAP
CASE STUDIES
HOME

Fill in your case details here:

Note: * indicates this field is mandatory

About the Home (Step 4 of 4)

* **Area of residence :**

Local Government Area (LGA) Outside NSW Within NSW

Postcode:
 (If in Australia)

* **Accommodation setting :**

Number of spaces associated: 3
 Space 1 (Bathroom general) [\[Edit details\]](#) [\[Delete\]](#)
 Space 2 (Bedroom) [\[Edit details\]](#) [\[Delete\]](#)
 Space 3 (Parking) [\[Edit details\]](#) [\[Delete\]](#)

[Add New Space](#) [Reuse Space](#)

Number of links associated: 1
 Link 1 (Stair) [\[Edit details\]](#) [\[Delete\]](#)

[Add New Link](#) [Reuse Link](#)

Particulars:

Attach Image - How many images?

1) Image Type :


Photo  [<< Delete](#)

Figure 8.19: Case acquisition: Step 4 - General home data

The home data acquisition form calls up the Accessible-Building model and captures data about the spaces, links, access points and services affected. Figure 8.20 illustrates the space pop-up when individual spaces are selected for more detailed examination. The form for spatial case acquisition attributes is designed to enable the user to enter as much or as little information as is relevant. The space type, shape links and access point fields are the only mandatory fields. For instance in this particular case it is evident that within the bathroom space, there are several services and an access point, which are relevant. Other cases may have more or less depending on the assessment of spatial barriers or type of housing redesign interventions intended.

About the Space	
* Space Type :	Bathroom general
Width:	2000 mm
Length:	3130 mm
Height:	0 mm
* Shape :	Square
Wall Particulars:	New plaster board walls with with tile finish to 1350 mm. Air conditioning unit removed and old window area bricked up. Wall F is new and contains a new semi-recessed vanity, shaving cabinet and folaway support
Floor Particulars:	New non-slip tile floor, height level with bedroom. Gradient 1:60 with floor drain.
Ceiling Particulars:	new compressed fibro false ceiling with cornice containing ceiling fan and lighting.
Intervention Particulars:	Bathroom has been extended to increase circulation space, the floor has been raised to bring it level with the bedroom which it adjoins and a new doorway has been installed with a sliding cavity door to
<hr/>	
* Services :	Assistive device Electricity Furniture (Hold 'Control' key (PC) or 'Command' key (Mac) while clicking to select multiple items)
* Access Points :	Hinged door Roller door Sliding door (Hold 'Control' key (PC) or 'Command' key (Mac) while clicking to select multiple items)
Access Points description :	New sliding door with recessed aluminum tracks now adjoins bedroom. Clear opening

Figure 8.20: Case acquisition: Step 5-Specific home space data

The last step in case acquisition is when all the relevant space and link pop-up are completed and the home form is automatically updated to include the space and link names. Then the user hits the 'Finish' button. This sends all the session variables to the database and once these are safely stored a feedback web page is automatically generated to inform the user that their case has been successfully acquired and is now sitting in the database.

8.4.2 Transformation knowledge storage and reuse

The HMMInfo casestudies prototype provides a unique contribution to CBR theory. Reusing a case means changing or revising features to ensure that the solutions fit the case-type intervention intent for a particular human in a particular environmental setting.

Transformations occur when the intervention intent, person activity or home features change. Storing these changes automatically produces new redesign transformation knowledge.

Traditional CBR approaches have failed to capture or reason with this knowledge, cases just being a collection of problems and solutions. However the CBR model underpinning the implementation prototype has provided a means of capturing transformation knowledge for browsing and reuse.

Figure 8.21 illustrates simple reuse knowledge acquisition by capturing the transformations undertaken when a source or base case is edited and reused. Transformation knowledge includes the details of the base case, the base case creator, the date of creation of the reuse case and the differences between the two cases.



Figure 8.21: Simple adaptation knowledge acquisition: Capturing redesign case-based reuse data

Nevertheless the changes or adaptations made may contain either radical or minor revision and could include attribute inclusion/exclusion and value tweaking such as parameter adjustment and/or value substitution. When the user makes these changes in the HMMInfo

casestudies prototype they are automatically stored as a part of the case as it is acquired. Figure 8.22 illustrates how more complex feature and value based redesign adaptation knowledge is captured and can be viewed as a pop-up. In the illustration provided, a home contained in the case library changed ownership (i.e. death or relocation of the previous occupant) and the new user had different impairment and activity requirements, thus assessment case contents differ in a number of ways. As can be seen, the reuse history catches all the data about any field changes when a case has been reused, such as:

- ▶ Attribute X deleted or changed from x^1 to x^2
- ▶ (i.e. attributes of ‘person 2’ deleted or attribute image type ‘plan drawing’ changed to image type ‘photo’ etc.); OR
- ▶ Value Y changed or left blank from y^1 to y^2
- ▶ (i.e. value of attribute ‘case-type’ changed from ‘assessment’ to ‘modification’ or ‘1.555 mm’ to ‘1.604 mm’ etc.)

All the variables that are changed are added automatically to the end of the new redesign case when it is stored based on its unique reuse history. For instance when an existing case is reused, its reuse history is automatically stored and these details can then be queried and browsed (see Figure 8.22). So case adaptation, while user driven, is thus potentially also available for data mining. In this manner, reuse history acquisition facilitates redesign learning and facilitates a better understanding of redesign practice. Transformation knowledge may be particularly helpful for prompting or guiding case-based reuse as it alerts a new user to features likely to require adaptation, depending on the proximity and intent of the base case.

Variable name	Source Case	Reuse Case
HACC Name	ronel	aloir
Case File No	P94/03835/01	P03/95643/03
Intervention Date	13 May 1994	30 Jan 2003
Intervention Cost	\$300.00	\$400.00
Total time	5 hour(s)	6 hour(s)
Sex	male	female
Age	67	44
Formal Care Services	Home help, Meals on wheels and day centre-based meals	Community-based respite care (mostly day care), Education and/or training information and advocacy services, Meals on wheels and day centre-based meals
Living Arrangement	Lives alone	Lives with family
Government benefit/pension	Aged Pension	Disability Support Pension
Primary medical diagnosis	Osteoarthritis	Alzheimers
Height	1.755 mm	1604.0 mm
Weight	82.0 kilograms	72.0 kilograms

Figure 8.22: Using adaptation knowledge to understand redesign reuse patterns

The reuse history also serves to link cases and thus provides a housing lifecycle history. For example, in reusing Mrs. McLean's assessment case, there are a number of features that differentiate assessment and modification type case contents. When Mrs. McLean's assessment case is reused and modified to store the new modification case contents this information is automatically stored as case variable type as illustrated in Figure 8.23. In this example, all the variables relevant to a real modification intervention are captured.

Variable name	Source Case	Reuse Case
Case Type	Assessment	Modification
Intervention Date	14 Feb 1995	2 Mar 1995
Intervention Cost	\$600.00	\$9,000.00
Total time	7 hour(s)	36 hour(s)
Activity(s) impaired	* Bathing (or showering) - Physical assistance required * Shopping - Dependent * Housekeeping - Dependent * Food preparation - Dependent * Laundry - Dependent * Transportation - Dependent * Stairs - Physical assistance required * Transfer - Physical assistance required	* Shopping - Dependent * Housekeeping - Dependent * Food preparation - Dependent * Laundry - Dependent * Transportation - Dependent * Stairs - Physical assistance required
Equipment provided/available	Wooden ramp at front, Electric scooter (Shoprider), adjustable walking frame (KA 350)	Plastic shower chair
Activity Enabled	Bladder,Bowel,Dressing,Feeding,Grooming,Telephone,Toilet use	Bathing (or showering),Bladder,Bowel,Dressing,Feeding,Grooming,Telephone,Toilet use,Transfer
Activity Particulars	* Ambulant at present using walker, at times unsteady. * Has difficulty climbing stairs and does not appear safe despite rails both sides. * Independent in personal care though exhausts easily. * Presently using a bath	The modification increased independence and safety. It enabled future bathing needs to be accommodated as condition deteriorates. It also reduced carer anxiety, and provided a safer work environment with adequate space to assist as necessary in future.

Figure 8.23: Reuse facility links case-types and stores housing reuse lifecycle

8.5 Evaluation of the redesign reasoning methodology employed in the prototype

The casestudy prototype was made public when the HMMinfo clearinghouse website was officially launched in November 2003. By September of 2004 there were 95 registered users, including Home Modification and Maintenance service providers (63%), Occupational Therapists (12%), Home and Community Care providers (7%), Local Government Associations (7%), Design students (5%), Consumer peaks⁸ (5%) and government authorities (3%). The breakdown of usage by professional discipline can be seen in Figure 8.24.

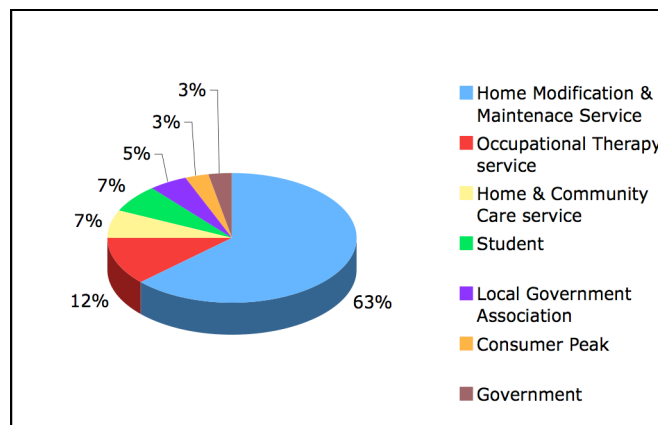


Figure 8.24: Distribution of HMM case registered users by professional grouping (Oct 02, 2003 -- Dec 08, 2004)

⁸ These are representative organisation, who are primarily accountable to its members. and speak on their behalf (e.g. Multiple Sclerous Association and Physical Disability Council).

Access to the casestudies prototype does not require that users register, however only registered users' can add cases. All data about registered users' was obtained by analysis of the user profile, which was voluntarily entered online. The fact that over half (58%) of all home modification services within NSW are registered users reflects their awareness of the casestudies areas existence via website rollout orientations and suggests that the majority of services believe the ability to share cases is a potentially valuable tool for learning about home modification interventions and thus improving service outcomes.

In evaluating the CBrR functions within the HMMinfo casestudies prototype the case-library was seeded with four assessment cases and one modification case. An assessment case was added by a registered user subsequent to this, making a total of seven cases available online. In seeding the case base (i.e. entering the basic home modification case data) necessary to evaluate reuse and browsing functionality, only very minor adjustments to attributes and/or field variable validation were required. These included minor modifications to the database. For example, within the 'Human' field attributes the 'medical prognosis' field was modified to include 'unknown/Not applicable' as was the field 'Receipt of formal services' which was extended to include 'None/not appropriate as these also applied to persons (i.e. care recipients or carers) who were not receiving services or who did not have a medical diagnosis. In addition, the 'Spatial' field attribute 'Access Points' was expanded to include a new field 'Roller door' to accommodate a novel door type not previously anticipated.

Further, two errors with the validation functions were noted and corrected. These related first, to the field 'case contents' and the operation of the attribute 'Cost of intervention (in whole \$)' and second, to the 'person' and the operation of the attribute 'height'. Both integer values were insufficiently sensitive to decimal place variance and so were being rounded down. For instance, if the user entered \$9,000.00 as the value for the 'cost of intervention (in whole dollars) attribute' it was stored and displayed as \$9.00, while if the user entered 1.555 mm as the value for the attribute 'height', it was displayed at 2.0 mm.

8.5.1 Web log analysis of performance

The WebSTAT page view⁹ logs were analysed in order to evaluate the casestudy usage patterns of registered casestudy users and visitors (non registered users restricted to browsing). The page views web logs pertain to the whole of the HMMinfo website of which the casestudies area is just a small component. In total there were 10,157 page views specific to the casestudies section of the website when the user registration page views information

⁹ WebSTAT is a statistical analysis program, it defines a "page view" simply as the number of times a page on a particular website was displayed. This count is incremented every time a visitor views or refreshes a page on a website that has the WebSTAT code tags on it.

was removed. This represents 40% (e.g., just under a half) of the total HMMInfo website usage. The fact that this percentage is so high suggests that there is considerable interest in a facility to share home modification cases online.

The breakdown of the page view statistics is shown in Figure 8.25. Web log analysis indicates that the act of browsing cases accounts for the largest number of page views (i.e. it accounted for 27% of the total casestudy page views). Additionally, the page views of H-A-S components ranged from 4-12% of the casestudy total. It appears that the casestudies users registered the highest number of page views for the general case components, followed by the *human* components and *space* components, The lowest number of page views were registered for the *activity* component. This implies that not all the users' viewing cases were equally interested in all the H-A-S components. Why this is so is unclear, it may reflect different professional interests or instead it may relate to the degree of innovation or data quality.

Viewing of the case reuse reports (104) was substantially less than the H-A-S components but this is unsurprising as not all of the cases in the casestudies area currently contain this component. Also of note, is the fact that the number of page views for browsing is higher than those for submitting new cases. This implies that the majority of users' may be more interested in browsing cases for lessons or novel information than they are in submitting and/or sharing their own home modification cases.

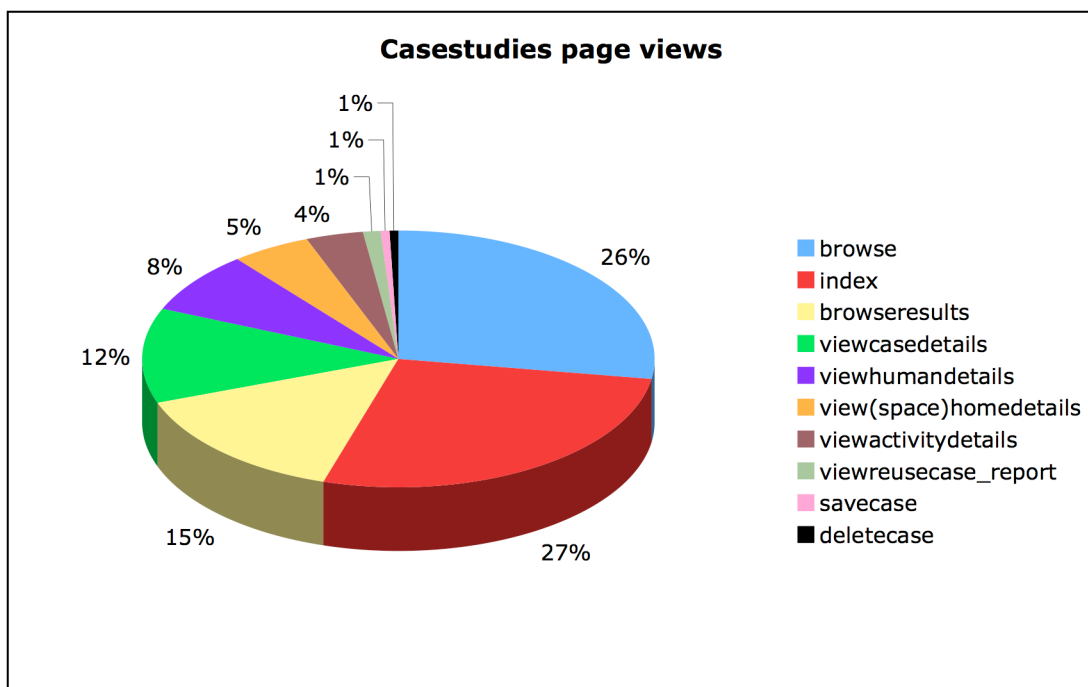


Figure 8.25: Breakdown of casestudy page views by page type and percentage of views (Oct 02, 2003 -- Dec 08, 2004)

Despite this obvious trend, a number of cases appear to have been added (50) but subsequently deleted (49). The total number of case added equals those deleted, if the cases currently available as submitted by users is subtracted. Why this occurred is unclear, it may just reflect a means of active exploration of the websites functionality. However, the fact that users deleted cases might also be attributable to their belief that they had insufficient case detail at the time (i.e. digital images, plans etc.), or it might instead relate to lack of client consent and/or fear of peer critique. It is also unclear if and to what extent, casestudy usage is or is not impacted by other factors such as age, geographical location, access to training, and/or disability.

As indicated at the beginning of this chapter, understanding the human impairment domain requires clearly distinguishing reasoning process from reasoning content. Human impairment reasoning sits across and relates the three disparate knowledge domains comprised of human, activity and space (home). The computation technology needed to construct a CBrR capable of dealing with disability domain problems needs to mirror disability methodology both in terms of reasoning tasks and knowledge. As can be seen in Figure 8.26, this means that the CBrR model within the HMMinfo casestudies prototype has to have the capacity to deal with problem sensing (assessment cases) and problem validation (modification and maintenance cases) while the case library needs to be able to relate the three discrete data sets required (i.e. one concerning human ability, one activity and the other concerning housing spaces). In figure 8.26, the arrows between components indicate the dataflow and reflect the relationship between reasoning and online actions. For instance, problem sensing uses browsing or search of existing cases to remind and learn which is why the data flow is from the database via the browse function. On the other hand, because problem validation requires real human, activity and space data, the user must submit the new data so the data flow is from the user to the database. The H-A-S knowledge is bi-directional, in other words it is used for browsing and case submission and so flows both ways.

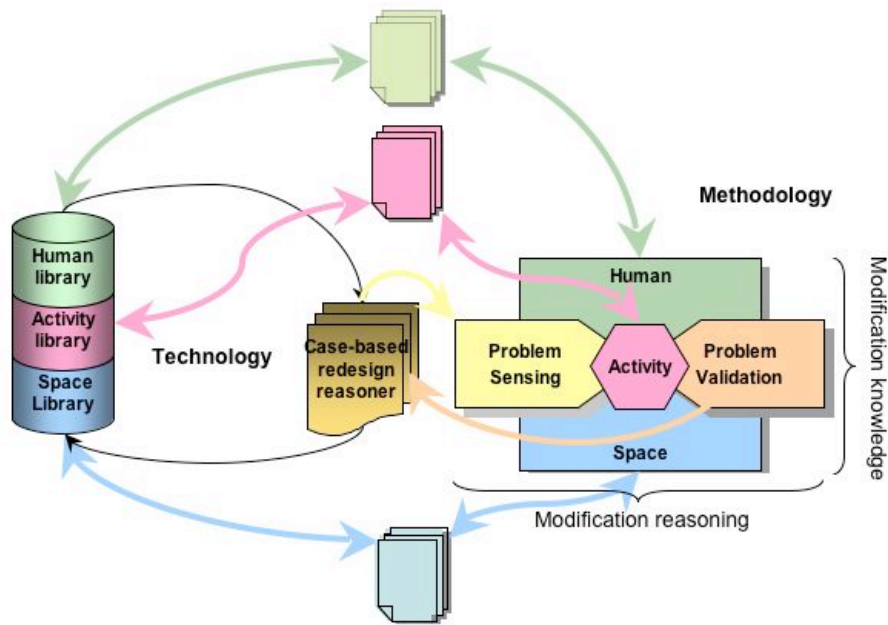


Figure 8.26: Relating disability methodology and computational technology

In applying a case example it is evident that the formal specification of knowledge and relationships facilitates reasoning and facilitates knowledge acquisition, browsing and reuse. It also facilitates a structure whereby case contents can be checking for accuracy, consistency and completeness.

8.5.2 Empirical evaluation of online performance

The case-based redesign system example outlined in this chapter, provides a web-based single point user interface. However a heuristic evaluation¹⁰ (Neilson, 1994) of the HMMInfo casestudies was undertaken to get more information about the overall usability, intuitiveness and efficacy of the system and its interface. This small scale heuristic evaluation was undertaken following the Web log analysis during the months of January and February, 2005. The evaluation involved six home modification practitioners in total. Half were experienced occupational therapists (3) working in a variety of settings and the other half were HMMS providers working within NSW. The purpose of the empirical evaluation was to explore the adequacy of the H-A-S model for managing home modification information. However this was implicit not explicit as the evaluation examined participants reactions to online reasoning tasks. The emphasis was on exploration, so it was not a full-scale usability study. All participants were already familiar with the casestudies area (i.e. were HMMInfo users) and volunteered to participate. Participants were purposively sampled, in other words HMMInfo users were generally emailed requesting participation in casestudies evaluation. Only those who emailed back an interest in participating were then sent a survey. In this manner all six

¹⁰ Problem analysis based on informal judgment or experience versus data manipulation.

subjects across the two professions were recruited. Participation was entirely voluntary and participation was solely for the purpose of providing some feedback to determine the key issues so as to better understand the way some users perceive the H-A-S model and the overall usability of the casestudies prototype's for home modification reasoning.

Each participant was given a specially developed HMMinfo clearinghouse 'Casestudy Usability Assessment' questionnaire. The questionnaire was based on the format and contents prescribed for online usability evaluation by Commonwealth government web portal developers (McGovern, 2004). Each participant was asked to provide information about their demographic profile; Internet experience and they were also asked to carry out two online tasks¹¹. The two tasks involved locating a case for reuse and submitting a new case. Tables 8.1- 8.3 list the responses to the questionnaire. Table 8.1 provides information about demographics; Table 8.2 examines prior Internet familiarity; and Table 8.3 shows information relating to task 1 (locating a case) and illustrates information pertaining to task 2 (submitting a new case).

Table 8.1: Demographic information

Participants demographics	Occupational Therapists	HMM service providers	Interpretation
What is your age group?	2 (21-30); 1 (31-60)	1 (21-30); 2 (31-60)	Both user groups are adults and the fact that the Occupational Therapists are marginally younger may be to do with the fact that those working in HMMs services tend not to enter as a first job. The age difference may also mean that the younger users are more familiar with computational technology.
Gender	1 male and 2 female	1 male and 2 female	The fact that these are the same is unexpected as traditionally there is a gender difference with Occupational Therapists being predominantly female and those from a construction background predominantly male.
What is your highest level of education?	1 Post Graduate Certificate; 2 Bachelors degree	1 Vocational Education (TAFE); 2 Bachelors degree	It appears that the Occupational Therapists have a slightly higher level of tertiary training. This is expected as traditionally construction trades are taught at TAFE.
Are you from a Non-English Speaking Background?	3 No; 0 Yes	3 No; 0 Yes	This is most likely an effect of the small purposive sampling and may not reflect the larger user group.
What is your main occupation?	3 Occupational therapist	2 Manager /Administrator; 1 Builder/Tradesperson	This is as expected, but implies that the HMMS users have a wider professional base than that of construction and this may impact responses.

¹¹ The full questionnaire as sent to participants is available in the appendices CD-ROM

Participants demographics	Occupational Therapists	HMM service providers	Interpretation
What region of your state do you live in?	3 Metropolitan	2 Metropolitan, 1 Regional	This is most likely an effect of the small purposive sampling and may not reflect the larger user group. The biggest limitation is that there are no remote users where internet connections may be more unreliable or slow.

Table 8.2: Prior Internet familiarity

Internet familiarity	Occupational Therapists	HMM service providers	Interpretation
How confident are you with using a computer? (Scale of 1-5; with 1= not confident and 5 = very confident)	4	4-5	This implies that those who volunteered to participate perceive themselves to have good computer skills. There appears to be a small difference between user groups, why this is so, is unclear. The overall high confidence levels may correlate to willingness to volunteer..
How confident are you with the Internet? (Scale of 1-5; with 1= not confident and 5 = very confident)	4	4.5	This implies that those who volunteered to participate perceive themselves to have good internet skills. There appears to be a small difference between user groups, why this is so, is unclear. The overall high confidence levels may correlate to willingness to volunteer.
Access location	3 Home; 2 Work	2 Home; 3 Work; 1 Community resource centre/library	It appears that most participants had access to computers at work, but not all had access at home and one HMMS users stated that they were accessing computers away from work. On one hand, an Occupational Therapist employed by the health system had no ready access to the Internet at work, while on the other hand, a Home Modification and Maintenance service participant had access to a computer at work but shared this with other team members.
Frequency of use	1 More than once a day; 1 Daily; 1 More than once a week	1 Daily; 1 More than once a week; 1 Weekly	The Occupational Therapists as a group appear to be slightly more frequent users but they also rated themselves as slightly less confident. However whether there is a correlation between usage and confidence is unclear.

Table 8.3: Task 1: Locating a case

Case location	Occupational Therapists	HMM service providers	Interpretation
Total time taken (mean score)	5-7 minutes	10 minutes	There appears to be a difference in the amount of time taken. Why this is so is unclear.
Case-type	2 assessment cases; 1 modification case	3 modification	

Case location	Occupational Therapists	HMM service providers	Interpretation
		cases	
Task accomplished	0 No; 3 Yes	0 No; 3 Yes	All users appeared to find the browsing task easily accomplished.
Comfort level (mean score)	Kind of fun	OK	This implies that the model components appeared to be understandable and the interface efficient.

Table 8.4: Task 2: Submitting a new case

Case submission	Occupational Therapists	HMM service providers	Interpretation
Total time taken (mean score, however not all users provided a value for this section of the survey)	15 minutes	25 minutes	There appears to be a difference in the amount of time taken. The amount of time taken may be attributable to the fact that the H-A-S components and the online presentation of components would be more familiar to Occupational Therapists than Home Modification and Maintenance administrators who will be more focused on spatial elements and who may be less familiar with human and activity data.
Case-type	3 assessment cases	3 modification cases	This difference may relate to differing professional responsibilities.
Task accomplished	1 No; 2 Yes	2 No; 1 Yes	Only half of the users actually added a case, this was because two users had trouble registering and one user stated they had insufficient time available to finish.
Comfort level (mean score)	OK	Ouch	This implies that that users don't find this task very difficult and the difference between the two user groups may be attributable to order of presentation of information and amount of time taken.
Was getting client consent a barrier?	1 No; 2 Yes	1 No; 2 Yes	This appears to be an issue of concern.
Was having to scan in photos or plan drawings a barrier?	1 No; 2 Yes	1 No; 2 Yes	This appears to be an issue of concern and may be attributable to lack of access to scanners and digital cameras in the workplace.

8.5.3 Analysis of open ended qualitative comments

Additionally, the survey questionnaire also yielded some open-ended written statements concerning general impressions and the like. These were categorised into positive and negative responses across five sections as seen in Table 8.5.

Table 8.5: Open ended feedback

Sections	Positive responses	Negative responses
H-A-S model	<p>“all good”</p> <p>“the type of activities impaired [is good]”</p> <p>“good to be able to select a case by person impairment...also selecting a case by activity impairment is another feature that I would find really useful”</p> <p>“there is sufficient detail and background information provided about the case to obtain a good idea about the client, their problems and suggested modifications etc. I found that the cases are very thorough in this respect”</p>	<p>“briefer and focusing on the main problems encountered”</p> <p>“Medical diagnosis, is this necessary; also details of client name code, height and weight”</p> <p>“is a need for brevity”</p> <p>“need ‘unknown/not stated’ option for pension status question”</p>
Reuse reasoning	<p>“re-used case versus the original source [is good]”</p>	
Case presentation	<p>“always a good looking site”</p> <p>“quite user friendly”</p> <p>“before and after pictures [is good]”</p> <p>“listed in a category form”</p>	<p>“some keywords were unclear, like “spaces” associated”</p> <p>“tables with wider cells would be better”</p> <p>“doesn’t excite or create a curiosity”</p>
User navigation browsing	<p>“easy”</p> <p>“good”</p> <p>“fine”</p> <p>“easy to navigate”</p>	<p>“a list of all current case types instead of searching with no result”</p> <p>“I would look for ‘innovative’ ideas in handling problems or issues. I want to know what works”</p>
User navigation adding a case	<p>“helpful hints – pop ups with the exact item that was incorrect [was helpful]”</p>	<p>“painful”</p> <p>“trouble logging in”</p> <p>“when saving person 1 it goes directly to person 2, should the ‘next’ button be at the top of the page as well?”</p> <p>“about the activity, it is not clear what to do, more instruction would be helpful”</p>

8.5.3.1 Interpreting feedback regarding H-A-S

As can be seen from the table, participants provided both positive and negative feedback. It is interesting to note that one participant stated that the activity part was good given that this component was the area of the H-A-S with the lowest number of web page views. The negative feedback can be broken into two types of comment. First, the issue of the number of components specified within the H-A-S model. Interestingly specific feedback relates to medical diagnosis, client id, height and weight. The rationale for inclusion of this information was outlined in section chapter 6, section 6.6. Without this information it would be difficult to search for a case, check validity of interventions for clinical appropriateness to client anthropometrics or to mine cases for any potential clustering of interventions on the basis of

medical diagnosis. For instance, at present it is commonly believed that the interventions for dementia and spinal injury are statistically similar despite different bathrooms and activity sets. Second, participants wanted additional drop down options including unknown as possible values for specific attributes such as income. It may also be that some of the HMMS providers do not have access to the level of detail about some of the fields required such as the person's height and weight. This is not surprising as this is still not a mandatory requirement of paper-based documentation.

Nevertheless, the fact that users have actually been able to enter and browse cases online implies implicitly if not explicitly that the attribute grouping in the H-A-S model does in fact provide a structure that makes sense to home modification participants. Further, the H-A-S model does appear to provide a framework and terminology capable of aggregating elements so that data can be acquired, browsed and reused successfully. Additionally, it appears to provide the necessary flexibility for clustering and interpretation of data elements at a number of levels of abstraction. In particular, the use of the H-A-S model assisted a uniform terminology for case acquisition and browsing that was familiar to Australians (i.e. Australian English), mirrored existing Home Modification and Maintenance practice (i.e. incorporated HACC and ABS data collection conventions familiar to service providers) and utilised common English terminology for capturing data (i.e. older rather than geriatric etc.) in order to more effectively communicate case-based data.

8.5.3.2 Interpreting feedback regarding reuse reasoning

There was one positive comment and no negative feedback comments noted. Thus it appears this is a feature of the casestudies area that participants appear to value.

8.5.3.3 Interpreting feedback regarding case presentation

While both positive and negative comments were noted, in balance participants appeared happy with the overall presentation. The negative feedback is primarily concerning small technical improvements with the exception of the comment regarding the lack of excitement engendered by a standardised presentation format. While this comment is important in terms of a standardised case presentation potentially not highlighting innovation sufficiently, this was not the intent of the casestudies area. Instead, a more standardised presentation format may have the advantage of assisting or eliminating double data entry, because it is more rather than less likely, to fit the documentation format expected of home modification practitioners in the future.

8.5.3.4 Interpreting feedback regarding user navigation browsing

The majority of users' appeared to be able to navigate the casestudies area without difficulty. Nevertheless, one user commented on drop down menus having more options than those that

are currently available. For instance a search for a maintenance case or for a rental property would currently produce no result. This is not an error of the navigation function per se but a limitation of case seeding initially undertaken when the casestudies area was launched. In addition the indexing of innovation is potentially problematic because what is innovative to a database is any information not previously stored but this may not match the required innovation anticipated by a participant as what is innovative to them is any case component with which they are unfamiliar.

8.5.3.5 Interpreting feedback regarding adding a case

The casestudies login issue was an unanticipated problem that appeared to be impacting participants' ability to add cases and which they experienced as frustrating. The users' who mentioned this problem were contacted and further explanation sought. With additional verbal feedback, it became apparent, that this process generated two types of different problems. For first time users', the computer generates a user name and password automatically (a six digit sequence of numbers and letters both the same). The previously registered user problem was directly, associated with the computational program, which failed to let users register a second time without remembering their original password. The new user registration problem differed and appeared to be associated with noticing that the user name and password were the same. This threw at least one user who had trouble because this violated their expectations of a typical login process and in this case their login failed because they attempted to enter their own name and then the automatically generated password.

8.5.3.6 Other qualitative feedback

The amount of time entering a case study while logged as under thirty minutes assumes that the case material is already documented and material is available in digital format. It appears that this time is additional to existing professional duties and this appears to be a critical issue with one user stating, "*it would have to be done outside of regular work hours*". The same user who commented about the need for case brevity also suggesting that they "*would like to use a proforma in word and port it on to the site*". This implies that double data entry is an issue.

Client consent was another unexpected barrier with varying feedback, one respondent stated "*that the case they wanted to enter had been on national television so this was not an issue*" but another user stated "*I had great difficulty in obtaining approval from my employer to approach my clients to see if they would participate... None of the clients that I approached were willing to participate..their reasons for not participating included the following; their houses were too messy to have photos etc. on the internet; don't want others seeing inside the house; and don't have time to participate-too busy*". The same user also reported that obtaining client consent and maintaining client privacy was a critical objective of their organisation.

Overall, users appeared to value the casestudies facility. The analysis of participant's open-ended written responses suggests that the layout, navigation and menus all appeared to perform adequately. All the casestudies Web pages were designed to use some colours to improve scanning and highlight buttons and links that contain actions. However use of red/green contrast was avoided (as this is the most common form of colour blindness) and all pages were printed in black and white so that they could be manually scanned for clarity and tested for the appropriate degree of contrast. Additionally, the whole site was designed to incorporate consistent page layout, recognisable navigation aids, and easy to understand language. As these benefit all users, particularly those who are less familiar with Internet usage.

However feedback from participants raised a number of important issues including the amount of time required to enter data and find cases being problematic as it was additional to their existing job demands. This was in a context where all participants mentioned heavy work schedules and casestudy usage is generally on top of normal duties. Case submission also meant a double up of data entry, as paper-based documentation is still the workplace norm. Additionally, a number of participants mentioned issues around the time associated with gathering case details from paper-based files and issues associated with converting drawings and photos to the digital format required for case submission online. Furthermore, gaining client consent is also a reason that cases may not be being submitted in the quantities originally anticipated, with several participants commenting that when they had approached their clients they were unable to get permission to submit case material.

8.6 Reflexive Summary

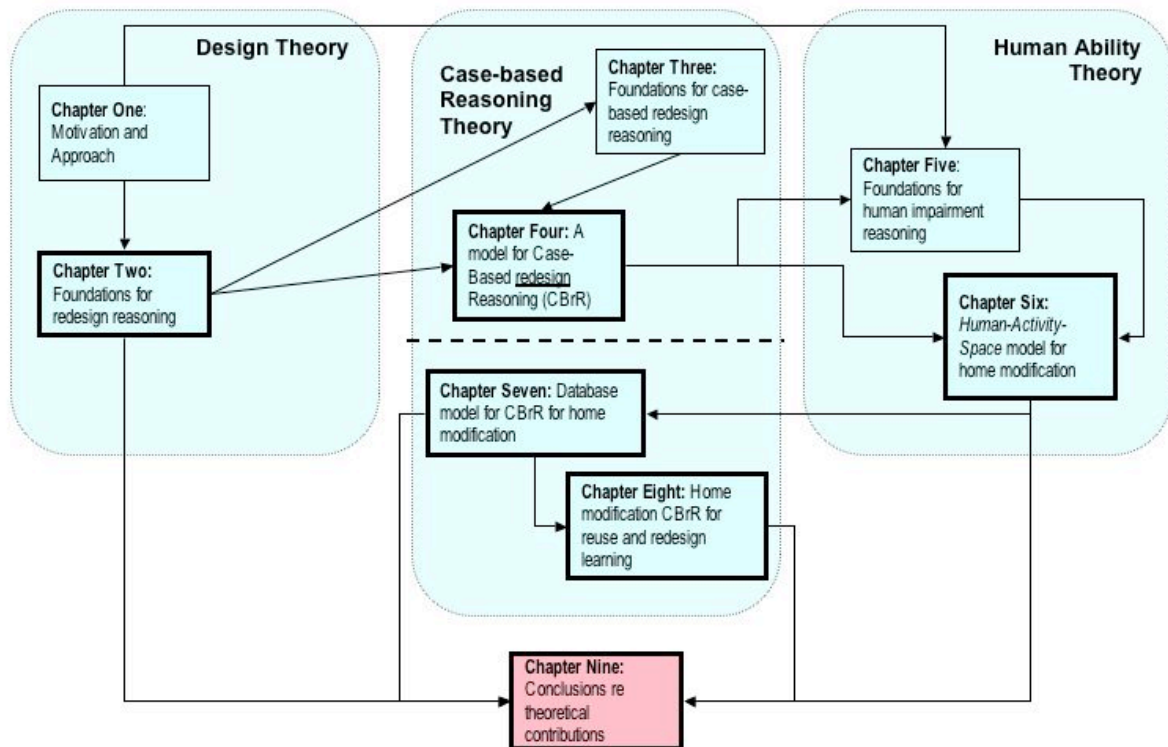
This chapter set out to explore whether the Human-Activity-Space database management system model for redesign could be usefully applied to home modification practice online by presenting and discussing how the web-based online HMMinfo casestudies prototype operating on and with human impairment redesign cases. It was clear that the system was technologically functional. The CBrR methodology enabled case acquisition; browsing, reuse and machine learning of redesign processes. Thus one means of solving the problem of the representation of episodic knowledge for this specific application environment was demonstrated. Further, this chapter also demonstrated implementation of the CBrR model,

The HMMinfo casestudies prototype embodies both the redesign focus and case content descriptions described in chapters four and seven. As a computational system designed to promote human ability it also provided the following:

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- ▶ a tool for measuring and reporting on aspects of housing relevant to improved activity outcomes for persons with ability impairments;
 - ▶ a means of capturing redesign transformation knowledge; and
 - ▶ a means of knowledge sharing and real world problem solving via provision of online cases.

Additionally, it presented an analysis of registered users', casestudy page views and an empirical evaluation of six purposively sampled home modification practitioners. This analysis indicated that, while there is substantial interest and a number of perceived benefits, there are also still a number of barriers to widespread Internet usage. These included the complexity of case formats (i.e. the details required are greater than that typically used in existing paper-based documentation), the amount of time required to locate and submit a case and other barriers such as needing client consent and converting material to digital formats.

9



Conclusions re theoretical contributions

Chapter 9: Conclusions re theoretical contributions

9.1 Introduction

The research outlined in previous chapters is summarised and the results obtained are related to the theoretical and practical contributions. A significant contribution resulting from this research is a useful working system for housing redesign for people with disabilities. The development of a working prototype is an important part of any project applying a CBR methodology.

9.2 The structure of this chapter

In this chapter, the findings, contributions and conclusions of the thesis and possible further research directions are outlined. There are four key parts to the structure of the chapter. First conclusions about the Human-Activity-Space model are explored in relation to both confirmatory and opposing evidence for their validity and functionality. Thesis achievements are summarised in regard to thesis objectives. Second, there is discussion about thesis achievements and limitations. Third, conclusions stemming from the work undertaken in the thesis are discussed. Finally, there is acknowledgement of issues stemming from this work that are worthy of further research. The application of the redesign paradigm illustrates the capabilities of the proposed approach and presents some of the implementation issues and their resolution.

9.3 Conclusions about the Human-Activity-Space model

This thesis presented the development of a case-based redesign model suitable for acquiring, recalling and transforming redesign knowledge, using case-based episodes for humans with impairments of ability. An ontological structure suitable for case-based redesign representation in the domain of redesign for people with disabilities was developed and presented. The ontology facilitated representation and navigation of redesign cases for reuse. Identification of appropriate cognitive and computational design methodologies were used as a basis for the development of new representation and navigation models for redesign. In addition, clarification of the theoretical relationship between design and redesign demonstrated critical differences in both process and product representation relevant to the development of a case-based redesign system.

However, it is also important to revisit some of the alternative perspectives raised in terms of their relationship to the work undertaken. In chapter one, the move to electronic health records was mentioned which implicitly raises the question of why, given the centrality of

human based case reasoning and these initiatives were not explored further. Some of the substantive similarities and differences between the Human-Activity-Space ontology versus electronic health records standardisation include the following:

- ▶ similarity in the need to structure data;
- ▶ similarity in the driver being ease of use, and online accessibility;
- ▶ similarity in reticence and reluctance of practitioners to move to online documentation;
- ▶ inadequacy of health record structures to guide redesign;
- ▶ inadequacy of health record structures to enable case-based reuse; and
- ▶ inadequacy of current electronic health record structures to define and describe the multiple uses of home modification case data.

Another area that was explored in chapters two and three was the issues associated with why design models are or are not appropriate for redesign reasoning. Some of the critical points from the examination of design and case-based models can be summarised as follows:

- ▶ inadequacy of design models to adequately capture redesign data;
- ▶ inadequacy of the existing case-based reasoning process to capture redesign data;
- ▶ oversimplification of human ability within design models; and
- ▶ potential for Human-Activity model application to design.

Finally, there are some significant conceptual similarities and differences between the Human-Activity-Space model and the ICF framework as explored in chapter six and seven. These are as follows:

- ▶ similarity in the desire to structure human, activity and environmental data;
- ▶ similarity in the driver being better classification, stronger theory and knowledge discovery;
- ▶ inadequacy of ICF to adequately capture redesign data;
- ▶ oversimplification of spatial features within ICF with a resultant absence of residentially relevant spatial descriptions; and
- ▶ oversimplification of activity features within ICF.

9.4 Thesis achievements

This thesis presents the development of a CBrR model. The research work undertaken within this thesis identified the need for integration of knowledge from the building and human response domains. The result of this work was the H-A-S model, which drew on the ICF, Activity-Space and Accessible-Building frameworks to bring together disability and design theory and applied this to redesign. Figure 9.1 takes the set of generic redesign tasks outlined in chapter four and maps them onto the knowledge required for a CBrR operating in the domain of housing redesign for people with disabilities.

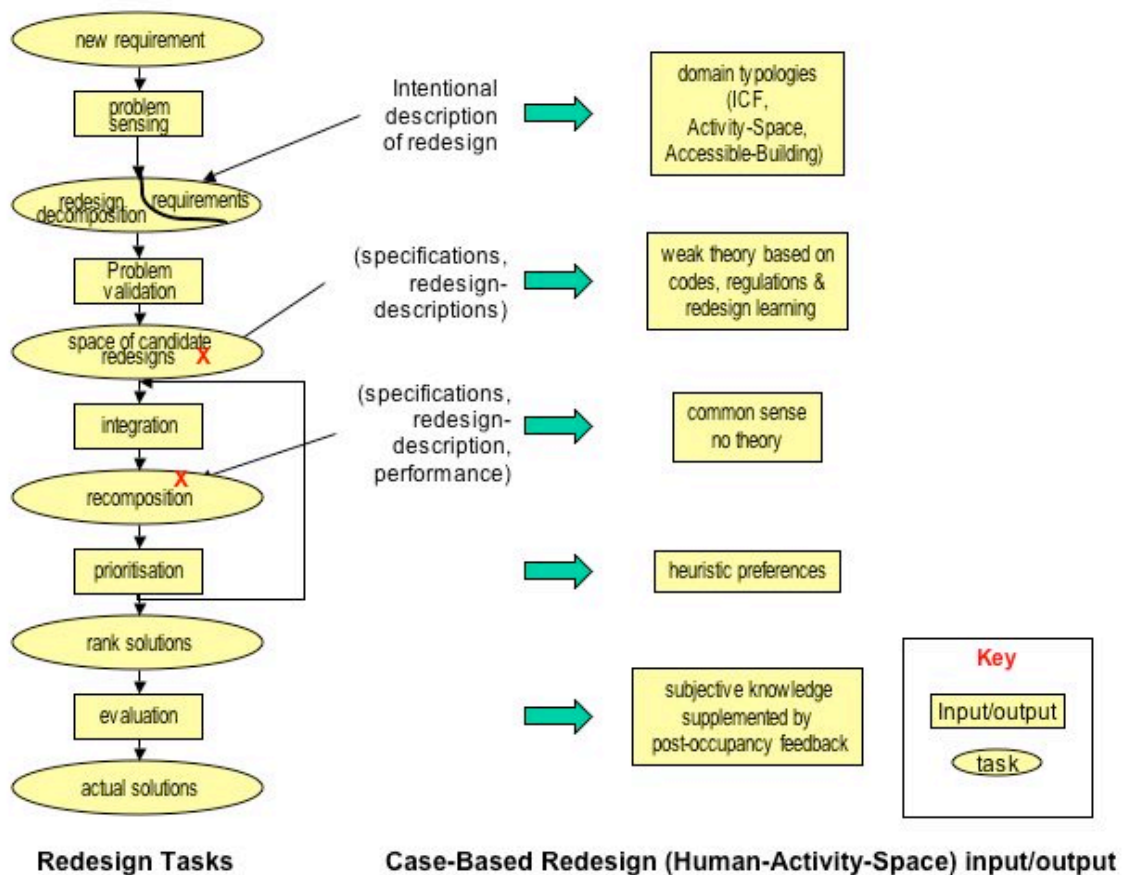


Figure 9.1: Mapping redesign tasks onto the subtask knowledge required to enable human ability.

The mapping of tasks to inputs and outputs concludes that the domain knowledge which was the primary input at the commencement of the research work stemmed primarily from experience and practice not theory, evidence or research. Moreover it shows how combining and extending existing theoretical work to produce the Human-Activity-Space model makes possible a more formal intentional computational description of housing redesign requirements and solutions.

As can be seen, given the absence of any strong theory in conjunction with reasoning based on heuristic preference and redesign learning, the primary contributions of this thesis are to the redesign tasks of problem sensing (assessment) and problem validation (modification and maintenance). Unfortunately, the lack of strong theory for the key process subtasks of integration, prioritisation and evaluation limits the ability to fully automate computational decision support.

The Human-Activity-Space model developed and then extended in this thesis provides a robust and flexible means of representing and reasoning about disability housing redesign. The Human-Activity-Space ontology can be used to create an activity centric means of linking the person and environmental attributes in a logically coherent and internally consistent fashion. The capacity to extend building and/or artefact measurement data to include human ability and activities allows users to better predict person-environment fit and begins to provide the groundwork for specifying parameters of preferred intervention solutions that could lead to more automated and better decision support in the future.

This thesis aimed to identify redesign principles that could be modelled for application to the domain of disability redesign reasoning. This thesis achieved this aim by satisfying a number of theoretical and practical research objectives. The research achievements can be summarised in the light of these objectives as follows.

9.4.1 Theoretical results

- ▶ Differentiations of design from redesign models, particularly with regard to representation and redesign learning (Chapter 2).
- ▶ Development of a CBrR problem-solving framework (Chapter 4).
- ▶ Development of the Human-Activity-Space ontology to enable representation of person attributes relevant to design/redesign architectural solutions for persons with disability (Chapter 6).
- ▶ Demonstrating integration of the CBrR model with the Human-Activity-Space model to enable acquisition, browsing and reuse of redesign housing cases for people with disabilities (Chapter 7).
- ▶ Demonstrating how a CBrR system could be implemented into a web-based, accessible computational environment (Chapter 8).

9.4.2 Practical results

- ▶ Implementation and evaluation of the Human-Activity-Space data model in achievement of an integrated and accessible approach to online collection; manipulation, customisation, analysis and reporting of housing redesign cases for older people and persons with disabilities (Chapter 8).
- ▶ Development and preliminary testing of a prototype case-based redesign system for home modification casestudies (Chapter 8).

9.4.3 Intellectual property pertaining to the research

Intellectual property results from the action-based inquiry process undertaken in the development of a computational case-based redesign for disability. The evolution of the set of features within the Human-Activity-Space model has come about through a significant contribution from the fields of disability, occupational therapy, case-based design and architectural design. The following are original outcomes from the research undertaken:

- ▶ The extension of case-based reasoning methods to capture redesign data (Chapter 4);
- ▶ The way that the data items within the model have been combined in and between case-type profiles to enable data reuse and the clinical/social/information logic that underpins this, including the interrelationships between the different data elements (Chapter 5);
- ▶ The selection and modification of the data items making up the Human-Activity-Space model (Chapter 6);
- ▶ The design of the home modification case-base prototype including data model specifications (Chapter 7); and
- ▶ Defining and describing the multiple uses of home modification case data, including the interpretation of Human-Activity-Space information to assess the needs of an individual or to aggregate that information to estimate the needs of a given population (Chapter 8).

9.5 Thesis Limitations

There were a number of irresolvable limitations of the action-based approach to computational simulation for housing modification. These included the following:

Methodological issues

- ▶ engaging in action based inquiry places the researcher at the centre of the inquiry process, as such the researcher is embedded in the research process and is not an unbiased observer (Chapter 1);

Environmental issues

- ▶ the rate and direction of computational innovation and change (Chapter 1);

Application issues

- ▶ the limited number and range of case-types made available as part of the initial case library seeding (i.e. five assessment cases, one modification case and no maintenance cases) (Chapter 8);
- ▶ lack of a systematic full-scale usability testing of the home modification case-based prototype (Chapter 8); and
- ▶ a reticence and reluctance of home modification practitioners to move online and publicly share case data (Chapter 8).

9.6 Conclusions

CBR is a helpful methodology when extended to provide computational decision support for redesign of housing cases. It has not until now been extended to encompass redesign. The redesign extension has demonstrated how redesign reuse knowledge can be acquired and stored. To be effective a CBrR has to represent domain knowledge such that it can be acquired, stored, browsed and reused. Redesign is a different entity, which partially overlaps with design.

There are a number of benefits stemming from clearly articulating a computational framework for redesign that enables human ability. These include but are not limited to:

- ▶ greater clarity of understanding;
- ▶ better management of resources;
- ▶ better basis for conflict resolution;

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- ▶ easier identification of what to aspects of a case require capture; and
 - ▶ improved confidence in decision rationale.

The research undertaken in this thesis goes some way towards improving the utilisation of redesign knowledge because it provides a method for exploration and structuring the uniqueness of each case-instance. In this manner it facilitates redesign learning and enables data to be shared. Hopefully the process of sharing and redesign learning will provoke inquiry and reflective practice that leads to greater efficiency and better client outcomes.

In considering the current state of theory concerning design and human impairment and the resultant issues surrounding redesign for persons with disability, the research undertaken within this thesis has presented a new view of redesign. Moreover it has extended the traditional design models to include human diversity and used activities as a basis for joining artefact and human representations, which enlightens several important aspects. Furthermore it extends an understanding and knowledge in regard to design, redesign, human response representation and CBR methods. It also contributes to real world practical decision support outcomes underpinned by web-based implementation strategies.

9.6.1 Design

In the field of design, the action-based exploration undertaken in this thesis highlighted the following:

- ▶ the existing structuring principles for articulation of design product and process representation are insufficient to capture redesign characteristics needed for redesign reasoning (Chapter 4);
- ▶ the field of building design simplifies human attribute representations by assuming one-size fits all (or at worst the majority of the population) (Chapter 5); and
- ▶ the feature taxonomies within the Human-Activity-Space model that require representation are in principle the same for both design and redesign (Chapter 6).

9.6.2 Redesign

In the field of redesign, the action-based exploration undertaken in this thesis highlighted the following:

- ▶ redesign reasoning is both knowledge and context dependent (Chapter 2);
- ▶ redesign can be differentiated from design. It has different representational requirements and knowledge components (Chapter 2);
- ▶ redesign cases need to contain descriptions that are composed of both the new requirements and the existing artefact description plus the redesign solution (intervention) description (Chapter 4);

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- ▶ the redesign process is a sequential arrangement of subtasks that facilitates redesign learning by providing a framework for redesign transformation knowledge acquisition. The distinct nature of the subtasks enables specific process knowledge and techniques to be applied concretely to the relatively fixed environmental context (Chapter 4); and
 - ▶ representation of redesign decomposition knowledge requires an ontology to express the structure and characteristics of the components (Chapter 4).

9.6.3 Human response representation

In the field of human response representation, the action-based exploration undertaken in this thesis highlighted the following:

- ▶ understanding and encoding redesign requirements for all humans, and people with disabilities in particular, means encoding attributes of the human performer (their abilities and body specifics) and attributes of the activity (type and quality) in relation to the environmental setting (Chapter 5);
- ▶ gathering detailed data about human responses to designed artefacts underpins all informed decision making and assists formulation of more widely generalisable design principles (Chapter 5); and
- ▶ the Human-Activity-Space model provides the basis for the terminological foundations underpinning the development of computational formalisms. The model integrates and extends current theoretical understandings based on the compositional requirements of case-based disability redesign (Chapter 6).

9.6.4 Case-based reasoning

In the field of case-based-reasoning, the action-based exploration undertaken in this thesis highlighted the following:

- ▶ the universality of some of the theoretical assumptions inherent in CBR were found lacking when considering redesign reasoning (Chapter 3);
- ▶ a CBR methodology provides an appropriate problem-solving paradigm for redesign by facilitating case-based learning and enabling case-based reuse (Chapter 3);
- ▶ recall of a redesign solution enables prior adaptation knowledge to be reused as the primary adaptation method; and case acquisition involves substantially different problem and solution knowledge being learnt (Chapter 3);
- ▶ reasoning based on redesign cases requires that any unique or additional attributes or processes within cases be explicitly defined and described (Chapter 4); and
- ▶ the use of A-V feature pairs organised according to the Human-Activity-Space model allows the creation of compositional cases that can be organised hierarchically into a variety of abstraction levels. Implementing a model alleviated some of the difficulties related to complexity of articulation while still providing flexibility in recall and a uniform structure for articulation of decomposition relations (Chapter 6).

9.6.5 Web-based housing redesign prototype implementation

In the field of the online housing redesign prototype, the action-based exploration undertaken in this thesis highlighted the following:

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- ▶ provision of a terminological framework for case contents representation flexible enough to represent both global and specific data as needed (Chapter 6);
 - ▶ encapsulation of the salient feature sets within the potential problem space presented by both human and environmental frameworks needed to enable appropriate feature-based recall and search (Chapter 6);
 - ▶ provision of structured browsing of case contents requires articulation of artefact, new requirement and redesign solution type classes (Chapter 7); and
 - ▶ ease of use, online accessibility and incorporation of multimedia elements considered critical to system functionality (Chapter 8).

9.7 Further research

The research undertaken within this thesis assists in making the domain knowledge and boundaries of specific housing redesign case instances communicable, available and reusable. This affords the basis for further extension and modification to the prototype case-library for housing redesign presented in this thesis. Additionally, and possibly more importantly, it enables the examination of contextual variables as the process of developing and refining a terminological ontology assists in isolating data features for further study. The following areas while not exhaustive, could prove fruitful for further developing the model and for applying it to better understand the relationships between humans, activities and environments:

9.7.1 Full scale usability evaluation

A limitation of the H-A-S model concerns lack of knowledge re its robustness and utility over a truly representative range of case instances. A number of HMMS providers have had an opportunity to trial the casestudies prototype while it was in development and they have consistently provided informal but positive feedback. However, randomly sampled or full-scale usability testing has not been conducted. The model's ultimate validity rests on an iterative process of experimental and field trials. Opportunities to collect feedback as a part of practice would provide valuable information needed to refine the model and could serve to more formally evaluate the approach taken. For instance harder evidence of relevance and efficiency of use could be applied to streamline the prototype and could shape future policy and procedure decisions in regard to HMMS practice.

9.7.2 Expanding the case library

Initial seeding of the case-base was limited (six cases) and all the cases were drawn from the same higher-level home modification service servicing the same geographic area. This means that for the system to be of greatest value the case-memory needs to expand to include cases from a wider variety of case-types, home types and impairment types. The more cases within the database the more helpful the system will become in terms of both reuse and redesign

learning. Expanding the case library so as to capture the widest variety of case instances is vital to testing the utility of the underlying conceptual and database models.

9.7.3 Addressing reticence and reluctance of practitioners to go online

The use of the Internet for dissemination and sharing of information has enormous potential. The majority of Internet research suggests Internet usage will increase dramatically in the future. However information exchange in cyberspace, is very different from information exchange in the real world and requires a critical understanding of the current real-world behaviour of the full range of stakeholders which comprise the desired virtual community. While studies often cite practitioners as a generalised class of individuals, it cannot be overlooked that, online communities are comprised of specific characters that individually, and collectively, exert influence on the environment. Thus further research into the power dynamics and functional roles assumed within the real world community of practitioners including organisational, managerial, and team-building roles are important. A critical understanding of this behaviour in cyberspace, as in the physical world, cannot be achieved without a good appreciation of the factors affecting the reasoning and current information strategies of the full range of practitioners involved in home modification problem solving. If Web site designers, industry, educators and government who are faced with the difficult question of how to support and encourage practitioners knew better how home modification practitioners communicate and the power politics behind this, they could design strategies to improve productivity, learning, and allegiance to online methods more effectively.

9.7.4 Data mining and model discovery

Having a case-base means that the data within the cases can be mined to further current understanding of person-environment fit. Data-mining would enable the exploration of patterns within the case-data and based on exploration of a rich case-based library could do much to answer questions such as, are the clients receiving a different intervention in terms of impairment, activity or home features. It is currently believed that home modifications can improve the physical independence of people with disabilities and reduce the care burden. Further research could use the expanded case-base to test these ideas. It would also allow comparisons of trends over time. Data extracted from cases that is consistent with current theoretical standings and that facilitates national and international comparisons is essential to support home modification policy development, service planning and outcome measurement. Having case-data available facilitates undertaking a more complex range of analyses.

9.7.5 Automating the reasoning process

Databases dealing with redesign would benefit if data elements pertaining to codes and standards were not embedded inside cases but instead were available in a separate database. Unfortunately standards and legislation are socially fixed so will always change over time. Automated linking of case contents to the most current construction or disability standards and regulations is important, as without this information it is impossible to cross check data elements for errors or completeness. An automated case checker that stands separately from the online database implementation could be developed and updated as changes occur. The chief advantage of this separation is that any updating that occurred due to changes in standards would entail changes to query values not changes to the database structure itself.

9.7.6 Proposed replications and extensions for the future

It would be pleasing to see application of the Human-Activity-Space model to other design or redesign fields such as public accessibility, interior design, boat design or car design.

9.8 Reflexive Summary

This chapter set out to explore the thesis contributions, both practical and theoretical. It presented the value and limitations of the working prototype and suggested some useful future directions. Small-scale empirical evaluation by users suggested that while some aspects were valued more work is required for the casestudies to reach its full potential. The contextual background to this research includes the fact that there is currently no standardised format for documentation, online or otherwise, of home modification cases. Additionally, functional assessment in health and home care have traditionally been gathered separately from those of a particular human's spatial environment, Moreover, the gathering of information about problems (assessment) and solutions (intervention) has also been de-coupled. This is despite the fact that in home modification practice they are naturally linked via individual case records. As stressed in chapter one, like navigation at sea, where reasoning about position requires data in the form of latitude and longitude, in home modification assessment and intervention are naturally linked and it is the intersect between them that is at the core of case-based redesign discovery and learning.

Nevertheless, home modification practice remains in the domain of human services departments where there are many service agencies, increasing co-morbidity of clients and thus greater complexity of intervention considerations. These factors have led to a consequent specialisation and a policy trajectory that is moving in the direction of developing a common set of tools and an information sharing culture mediated by information technology. This future climate is one of both great challenge and great promise. The research undertaken

within this thesis, indicated that considerable raw potential exists but for this to be fully capitalised, more work is required, both in research and practical terms.

More qualitative and action-based research using web logs, demographics and full scale usability testing would allow a better understanding of attitudes to technology, user satisfaction etc. An action-based approach would lead to practical changes. For instance, improvements to the user interface might enable more dynamic responses. At present, the system does not change or display information differently for its users irrespective of their professional training or assumptions (i.e. administrators, builders and/or occupational therapists). So imagine if the professional designation of the user generated more professionally relevant data instead. For instance, a contractor or building professional might like to interact with *spatial* information first and only after this might they want to add or explore, *activity* or *human* data. Also, better developing a means of highlighting and categorising innovation would mean that the casestudies tool would be of greater interest and relevance to its users. Finally being able to achieve this without having to handle or enter data more than once but instead acquiring it automatically while a user prepared case notes or a summary report would assist in integrating casestudies reasoning into daily work and drastically reduce the current issues surrounding additional time demands.

Glossary of terms

Terms	Definition
Abstract case	A case represented at a high conceptual level.
Adapter	This is a constraint satisfaction technique in which a case is adapted to fit a new context.
Adaptation	Means to change something so that it is suitable for a new use or situation. In case-based reasoning it means modifying a previous solution for a new problem and typically refers to a particular method applied to change a case for the new situation.
Analysis	A method that separates a problem into its parts in order to identify it or to study its structure; or to examine and interpret it.
Assistive technology	A technology that is applied to increase or improve functional capabilities of individuals with disabilities. It enables a person to live at home and in the community, and enhance independence.
Attribute	An attribute holds data, either a named value or relationship that exists for some or all instances of some entity or feature cluster and is directly associated with that instance. An attribute described at the lowest level descriptor in a semantic descriptor hierarchy, in other words, it cannot be further subdivided.
Browsing	Means to examine items in a casual leisurely way
Cardinality	Refers to the number of elements in a logical or mathematical set.
Case	A case is an instance or example of the occurrence of something. It generally represents a concrete situation in context, integrating a multitude of complex information in a very concrete manner.
Case acquisition	A process of encoding case data.
Case-base	A collection of previous problem solving methods stored in a database.
Case-based reasoning	Is a methodology that uses previous problem solving situations as the basis for solving a new problem it is also a form of machine learning.
Case-memory	Is a computer representation of case-specific knowledge,
Case-part	Is a physical, replaceable part of a system that packages implementation and provides the realization of a set of features classes clustered conceptually.
Concept hierarchy	A hierarchically organized collection of domain concepts. The organizing relationship between concepts is "part-of" relations.
Conceptual model	Consists of the observations, mathematical modelling data, and mathematical (partial differential) equations that describe the physical system.
Concrete case	A case located at the lowest level of abstraction.
Constraints	These are semantic conditions or restrictions that compel or oblige a particular choice.
Context	The circumstance in which an event occurs.
Computational model.	The computer program or code that implements the conceptual model
Data	These are facts or information to be used as a basis for reasoning.
Data set	An identifiable collection of data
Data type	A specification of the legal value domain and legal operations allowed on values in this domain,
Decomposition	The process of dividing a complex problem into simpler sub-problems by separating a particular object or instance into its base elements.
Deinstitutionalisation	The policy of releasing people from large institutions, especially mental health and developmentally disabled persons into community based housing.
Design	A process of generating a description of a method or methods that

Terms	Definition
	satisfies a particular set of requirements.
Dimensions	Refer to quantitative, dimensional properties of a concept component. They typically refer to a measurable extent such as length, breadth, thickness, area, or volume.
Disability	A limitation, restriction or impairment that restricts everyday activities extending over a minimum period of six months.
Distributed	Means to spread or scatter, or place at different points.
Domain	A well defined set of knowledge characterized by a unique vocabulary. Typically relating to a discipline or problem-solving speciality.
Feature	A feature always contains one or more attributes. A feature is an abstraction of real world phenomena, which may occur as a slot, type or an instance.
Formalism	A set of modelling concepts used to describe a conceptual model. In computational terms, a formalism represents domain-specific nodes and links.
Frames	In computational language a frame is a collection of semantic net nodes and slots that together describe a stereotyped object, action or event.
Function	Is the special activity or purpose of a person or thing,
Generalisation	A taxonomic relationship between a more general element and a more specific element.
Goal	Objective criteria that humans and computational machines set out to achieve or to reach or to capture.
Grabrail	An Australian technical term used to mean a rail used to give a steadying or stabilizing assistance to a person engaged in a particular function.
Graph-structured feature vectors	In computational language, graph structured feature vectors are binary arrays of coordinates used to store and related features in multidimensional feature-space. Comparison of features proceeds by calculating distances between related information mathematically.
Hierarchical	Means of or arranged in a system with grades or status or authority ranking one above another in a series.
Home modification	Refers to change(s) or alteration(s) made to dwelling because of a disability, this may include, kitchen, bathroom and laundry fixtures, structural and architectural changes, and access alterations.
Hybrid	Means the use of multiple knowledge representation paradigms and/or reasoning paradigms in a case-based reasoning framework.
Implementation	Refers to the realization of a particular set of specifications.
Index elaboration	A process that expands the set of initial specifications through searching model memory.
Index revision	The process of changing the initial specifications by searching case memory.
Indexing	Means the identification and labelling that allows useful and efficient access to attributes that a previous problem should have in order to be relevant to the new problem.
Matching feature	Means a feature that occurs in both the new problem specifications and a case.
Method	Refers to the type of implementation of a particular operation or task process.
Model	Means the identification and labelling that allows useful and efficient access to attributes that a previous problem should have in order to be relevant to the new problem.
Modification	A process or procedure that makes partial changes.

Terms	Definition
Multimedia	Refers to the combining various media, such as graphics text, video, and sound in a single presentation or database.
Navigation	Means to direct the course of a particular action such as online wayfinding.
Ontology	A specification of a theoretical or computational conceptualisation that describes, defines and orders (i.e. 'is part of' etc.) domain entities.
Pattern matching	The process of using identified features to extract relevant cases from the case-base.
Paradigm	This is something serving as an example or model of how things should be done.
Presentation	Is the act of showing or revealing something, in computational terms it refers to what the human user sees and interacts with.
Process	Is an abstraction of a problem solving process that identifies the major subtasks, it typically refers to a series of actions or operations used in making, manufacturing or achieving something.
Product	Is an artefact, something created intentionally or unintentionally as the result of applying a particular process or set of processes to raw material.
Realisation	The relationship between a specification and its implementation.
Reasoning	The act of thinking, understanding and drawing conclusions.
Recall	Means searching to bring back into mind, to remember or cause to remember. In case-based reasoning it refers to the process of identifying a previous design that is relevant to a new problem.
Redesign	A process that requires decomposition of an old design followed by modification or adaptation of the original design.
Relationship	Refers to the semantic connection among model and/or feature elements.
Representation	Is a set of syntactic and semantic conventions that exemplify or embody something, making it possible to describe things. In case-based reasoning it comprises the form in which the case is stored in the computer as part of a case base.
Retrieval	The process of extracting (stored information etc.) from a case memory based on a whole case or a case subset of particular features of interest to the new problem situation.
Reuse	Means to use again.
Reverse Engineering	The process of analysing an object system to identify the system's components and their interrelationships so as to create representations of the system in another form or at a different level of abstraction.
Search	Means to look or go over (a place etc.) in order to find something.
Selection	The process of ranking in order to pick a case for reuse in the new problem situation.
Semantic net	In computational terms denotes objects by labelling them semantically as nodes and their associated relationship links.
Similarity	Means of the same kind, nature or amount.
Situation assessment	Means interpreting a new case or query and elaborating its representation to bring its description more into line with what might be stored in a case library.
Structure	Refers to attributes that are the physical properties of a design entity or the way in which something is constructed or organised.
Symbolic	Means using a mark or sign with a special meaning, such as mathematical signs.
Synthesis	Refers to the combining of separate parts or elements to form an alternative design solution.

Terms	Definition
Transformation	The process of modifying of a problem description by putting it into another form.
Value	The element of a feature type domain.
Weighted count	A selection method where the weighted sum of shared features is used to identify the best case.
Wellbeing	This is more than a state of being well; both words conjoined imply a state of balance or harmony within a person.
World Wide Web	A collection of Internet sites that offer texts, graphics, sound and animation resources through the hypertext transfer protocol

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Appendices

Index of thesis CD-ROM

Provided on the accompanying CD-Rom in PDF format for reference and clarification purposes are the following appendices:

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- ▶ Examples of the cases used to seed the HMMinfo casestudies library
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 - Blank form
 - Example of user feedback
 - Client consent for case contents to go online
- ▶ Publications directly relating to the thesis
 - Bridge, C., Kendig, H., Quine, S., & Parsons, A. (2002). *Housing and care for younger and older adults with disabilities* (Final Report). Sydney: Australian Housing and Urban Research Institute (AHURI), The University of Sydney Research Centre. February 2002, [on-line] Available from <http://www.ahuri.edu.au/publish/page.cfm?contentID=30&projectid=39>
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