Digital Curation Centre SCARP Case Studies ISSN 1729-586X

Digital Curation approaches for Architecture.

SCARP Case Study No. 6

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DCC SCARP INTERIM CASE STUDY REPORT
Deliverable B4.8.1.1

Version No.	1.0
Status	FINAL V2
Date	5 November 2009

Catalogue Entry

Title Digital Curation approaches for Architecture
Creator Colin Neilson (author)
Subject Data curation; repository services; design disciplines; architecture; disciplinarity; digital working
Description Case Study produced by the Digital Curation Centre (DCC) SCARP project, funded by the Joint Information Systems Committee (JISC).
Date 30 October 2009 (creation)
Type Text
Format Adobe Portable Document Format v.1.5
Resource Identifier ISSN 1759-586X
Language English
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Citation Guidelines

Neilson, C (2009), "Digital Curation approaches for Architecture", SCARP Case Study 6, Digital Curation Centre, Retrieved <date>, from http://www.dcc.ac.uk/scarp

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Executive Summary

The digital tools and methods of working adopted in the teaching, learning, research and practice of Architecture have resulted in digital assets which require appropriate treatment if the full value of the assets is to be realised. Value lies in current uses, such as design practice, understanding and research and also in the creation of an adequate record of architectural work that survives to inform future work.

This study aims to highlight choice in digital curation approaches, choice in how to provide appropriate care for digital objects, as a means of promoting more effective current and future architectural practice and research.

Architecture is a significantly challenging area of human endeavour. The digital methods and tools that predominate are not specific to architecture but in a business context are commonly used over the whole of an industry supply chain e.g. construction industry use of CAD based systems. In architectural research work the methods used include those of the natural sciences, social sciences, art and design, history and critical analysis. There is a significant element of research through design where the design process is itself a method of research recognised as practice-led research. The research problems tackled often require inter-disciplinary collaboration, e.g. architectural research contributions in social and economic regeneration projects.

Currently there is no national service for research data generated in UK Higher Education architecture departments. But the departments themselves have, in various ways, provided for the ongoing storage of digital assets produced as a result of research, learning and teaching. The 'learn by doing', 'design by making', practice-led research methodologies have encouraged production and use of multimedia resources as a means of gaining a collaborative design experience. This study suggests a curation approach that embeds the infrastructure required to support curation in the workflow, applications and tools commonly used by architectural practitioners in teaching, learning and research. The example of the European MACE (Metadata for Architectural Contents) project is indicated as exemplifying a service based on a federated approach to search and resource discovery over distributed architectural repositories of digital assets. Any proposed UK higher education national research data service would need to demonstrate the benefits to subject domains such as Architecture, at a subject and departmental level, of taking part as a contributor of content.

One measure of maturity in a given sector, or maturity of professional practice, is the degree to which there is an infrastructure that helps manage the burden and cost of care of digital assets as against the value and benefit to be obtained in current and future exploitation of digital resources. The digital curation treatment is required to be appropriate

to the practitioner's working methods. The development of purpose designed repository systems supporting interoperability and federation across individual repositories through networked repository services needs to fit the requirements of a domain such as architecture (or design disciplines in general). Repository services are required to underlie the flow of work undertaken by designers or architectural researchers without distracting from the given design or research task in hand.

Producing digital assets and sharing data are not the primary objectives of architectural researchers or of designers. The primary goal is more focused on increasing understanding and realisation of good design, often in a built environment context, informed by knowledge of the uses and meaning of buildings and places for users and communities in a modern society. The digital curation approach suggested is that curation be applied at the boundaries of domains (private, shared/collaborative, public) and at key phases of projects with support through automation of curation processes. In order to be viable the burden and effort of curation needs to fit the pace of project activity and be seen to produce tangible benefits during the project as each stage comes to fruition. The digital assets generated in architectural research, teaching, learning and practice represent a considerable investment which practitioners should be supported in exploiting to realise benefits.

RECOMMENDATIONS

Recommendation 1: that the Digital Curation Centre consider approaching the National Platform for the Built Environment to explore promotion of work to identify the digital curation standards for data and metadata exchange required to support digital models, including appropriate consideration of provenance requirements and processes such as preservation analysis. [Section 4.6]

Recommendation 2: that in preparation for a federated approach to networked search and resource discovery the Digital Curation Centre should collaborate with relevant Higher Education Institutions and Subject Departments, Research Councils and architectural professional bodies such Royal Institute of British Architects (RIBA) to influence guidance to institutions, researchers and practitioners on planning and managing the curation of digital assets produced in architecture and that this is carried forward in guidance for Continuing Professional Development programs. [Section 5.1]

Recommendation 3: that JISC invite European MACE project representatives to an appropriate JISC repository forum to explore the development and future of the services developed in the MACE project including lessons learned and consideration of the possible extension beyond the architecture subject domain. [Section 5.10]

Recommendation 4: that curation advocacy organisations, such as the Digital Curation Centre, take every opportunity to set out their view of the curation services required to support a federated cross institutional resource and discovery service for networked repository services covering specific subject domains, such as architecture in the UK Higher Education sector, in light of the developing digital repository infrastructure. That this should be done in alignment with the appropriate JISC programs and any initiatives, such as the United Kingdom Research Data Service, supporting national services for the care and exploitation of digital assets including research data. That this advocacy work be coordinated both with appropriate European Funded initiatives and with the UK bodies representing the designated subject community. [Section 6.5]

Recommendation 5: that the Digital Curation Centre seek to develop examples of Data sharing agreements and templates, in addition to data management plans and templates, as a means of developing an understanding of digital curation regimes sensitive to information rights management at point of use. That any exemplars of automated methods used to support data sharing agreements, resulting from projects such as the Consequence project, are included in the curation advocacy work with the aim of supporting requirements for trusted digital environments. [Section 6.7]

1 Introduction and background

The DCC SCARP project aims to understand the different approaches to sharing, curation, reuse and preservation of the results of digital working found in a variety of disciplinary fields.

Many previous studies[1] have highlighted disciplinary differences in relation to research practices and to scholarly communication in the digital environment. Part of the motivation for the SCARP project is to contribute to an understanding of how digital curation practices may be undertaken in a way that is appropriate to the variety of research cultures in the different research fields and teams. This is a central concern to the work of the Digital Curation Centre. What is the disciplinary landscape in which digital curation techniques may be usefully applied?

Architecture has a longer history of use of digital methods covering research, teaching and professional practice than many other subjects. It has developed techniques and methods of working in concert with cognate subject areas, Art/Design/Architecture (ADA) Architecture/Engineering/Construction (AEC).

Digital objects in architecture take the form of data, tools and instruments including software, work products (such as sketches, drawings, plans, models, visualisations, specifications and instructions) expressed in (and communicated through) particular forms of digital media. Digital working supports collaboration in the process of making designs as well as giving rise to digital products. These digital products may be the form of outcome delivered to the contracted partners, clients or customers. Digital media are used extensively in presentations of the work and have a strong role in promoting the work of the architect or practice (for instance through a practice web site[2]).

Digital working in architecture does not exclude analogue forms of working; for instance physical or tangible scale models[3] are produced by architectural model makers as a practice distinct to virtual modelling with digital tools and formats. The care of digital objects forms

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[1] For instance the research survey report by Sparks, S. (2005). JISC disciplinary differences report. Technical report, JISC.
http://www.jisc.ac.uk/media/documents/themes/infoenvironment/disciplinarydifferencesneeds.pdf

[2] For a typical example see Rogers Stirk Harbour + Partners at http://www.richardrogers.co.uk/ with a web portfolio of work including a list of “all works” with an online searchable keyword index.

[3] See http://en.wikipedia.org/wiki/Architectural_model for use of physical models in Architecture. Collections of these models can form part of the history and record of Architecture see http://www.vam.ac.uk/collections/architecture/where_study/architects_models/index.html for the collection on display at the Architecture Gallery in the Victoria and Albert Museum.

part of the requirement for a record of architectural work, both for audit and future use, as well as a means to gain most value and benefit from current work and intellectual property. The context for this care of digital objects is often found in hybrid forms of working where analogue forms (e.g. drawings on paper) are produced as well as digital objects.

This study aims to promote understanding, through review of case studies and the existing literature, of the variety of digital curation practices currently found to be in place in architecture. In line with the work of the Digital Curation Centre the study aims to make recommendations supporting the choice of digital curation approaches available for promoting more effective current and future research & practice.

In trying to characterise the current landscape of digital working in architecture there is a complexity of institutional setting; for instance in education the dual sector of further and higher education, in economic sector as a creative industry and as a constituent of the construction industry (built environment), in professional terms of architectural practice in the private and public sectors.

In each institutional setting architecture as a subject, industry or profession has a history of combining multi-disciplinary working with adoption and innovation of techniques as each generation of digital technology has emerged. In this wider context this study has tried to reflect a plurality of interests, avoiding prescription of any single approach to digital curation; this is appropriate given the extensive field of knowledge represented by architecture as it is taught, researched and practiced in the UK and internationally.

1.1 Digital Curation approach including research themes and questions

A working definition of digital curation including stages, processes and activities is set out in the Digital Curation Lifecycle Model[4]. At the core of this is the care of data, digital objects and databases. Architecture is a subject area that works with and produces complex digital objects.

The broad themes of the SCARP case studies are:

Policy drivers and barriers: Organisational and institutional factors including different skill levels, deposit and preservation policies and arrangements, willingness to use these and the relationships to incentives and reward structures within disciplines.

Stewardship practices: The research process and methods; how these relate to the digital objects created (e.g. data, drawings and models, software tools and methods, repositories and databases). How the digital assets produced (outputs) are used (including reuse and

[4] See http://www.dcc.ac.uk/docs/publications/DCCLifecycle.pdf

sharing) and linked to publication. Attitudes to doing this and to the usefulness of prior data, and the sustainability of collected digital information.

Tools and infrastructure: the tools and facilities used to collect, deposit, find, cite, discuss and annotate the digital objects and to ensure persistence and preservation over long time periods.

Preserving context: how communities of practice and their knowledge bases can be characterised, and how understanding of the lineage and provenance of digital objects may be documented.

1.2 Digital objects in Architecture

In many scientific disciplines a canonical understanding of digital objects is expressed through collection and care of data (obtained, for instance, by experimental methods). In a design discipline like architecture (with one part of its heritage in the Art/Design/Architecture constellation of subjects) the understanding of digital objects is more directly mediated through visual representation in producing sketches, plans, models, specifications and instructions as outputs from a design process.

One of the first uses of computer methods in architecture and the construction industry was to replicate traditional ways of representing building or built environment information through two-dimensional drawings, perspectives, engineering calculations etc. The computer tools used have tended to be separate applications for each function. This does lead to challenges of interoperability.

In architecture (with its role in the Architecture/Engineering/Construction (AEC) sector) the issue of how to structure digital information to allow communication (including sharing of data, specifications and instruction) has been a priority for both industry-led and international standardisation efforts[5]. One approach is to seek to integrate the whole design process, and workflow, in a single application framework. This integrated approach seeks to provide for representation of information, in digital form, throughout the life of a construction project or indeed the whole life of a building, starting from knowledge about design intentions and stages of defining a brief. This approach adopts object-orientated techniques, from software engineering, to produce digital building descriptions as formed building product models. Software vendors have adopted versions of this approach

[5] As an example of such efforts in standardisation see "BS 1192:2007 Collaborative production of architectural, engineering and construction information. Code of practice", http://www.bsigroup.com/Shop/Publication-Detail/?pid=000000000030163398. See also the outline at http://en.wikipedia.org/wiki/BS_1192

developing a class of product in the category of Building Information Model[6] (BIM) tools (for instance Autodesk[7] have developed Revit). This is intended to improve design workflow through architecture design software and also to build a market for BIM tools in the AEC sector by supporting all design phases, construction documentation and fabrication.

The critical aspect of a BIM approach is the move from more traditional modes of working to utilise shared product models requiring the partners and contractors in a project to change business processes rather than just aligning technology through a common tool. One benefit is that authorised changes can be automatically updated across the project through the building design and documentation system. An integrated model can also support detection of clashes (conflicts) resulting from design changes prior to commitment to the construction stage, with the potential to decrease the need for reworking what has already been built. The digital assets created in design and construction will continue to support the use and development of the building throughout its lifetime, including facilities management functions, with a BIM system held by the manager or owner of the building.

From a digital curation perspective BIM approaches lead to the creation of digital analytical objects. Digital Analytical objects are a form of complex digital object where the data, models, algorithms and sequences, audio and video or other visualisation, are delivered and maintained in a digital environment as a package that allows users to change parameters, or add data and objects, in a controlled way, to obtain a variety of outputs, or model a variety of scenarios. In a product design context the rights to changing and building the model may be controlled under an intellectual property regime. Houghton[8] has drawn attention to the importance of sharing data, models and other digital analytical objects as an increasingly important part of research and scholarly communication.

[6] For one explanation of the definitions for a BIM (Building Information Model) from the buildingSMART alliance see http://www.buildingsmart.com/bim. For a list of BIM definitions (with a list of BIM software tools) see http://bim.arch.gatech.edu/content_view.asp?id=402 .

[7] For product information on Revit see http://usa.autodesk.com/adsk/servlet/index?id=3781831&siteID=123112

[8] The term "digital analytical objects" was introduced in Houghton, J. et al. (2009). "Economic implications of alternative scholarly publishing models: exploring the costs and benefits". See http://www.jisc.ac.uk/publications/publications/economicpublishingmodelsfinalreport.aspx

2 Organisational setting (Educational, Professional, Industry, Research Contexts)

The approach to digital curation for architecture is influenced by the scale and complexity of organisation, forms of working and product over multiple organisational settings. Architecture is taught and researched in Higher Education, practised as a profession in a business setting (e.g. the architecture firm), achieves its built environment product in working with the construction industry sector.

If the teaching and research base for architecture is relatively small, with architecture firms predominately existing as small to medium sized enterprises, any suggestion of a digital curation approach based on dedicated staff carrying out digital curation role may be less likely to succeed. Such settings may require a sheer curation[9] approach where curation activities are quietly integrated into the normal work flow of those creating and managing data and other digital assets.

2.1 Brief characterisation of UK organisational settings for Architecture

The UK institutional landscape of organisations with material interests in the survival and effective use of an architectural record, including the digital record, is complex. It includes (amongst others):

- Collecting institutions, archives and libraries e.g. the Victoria and Albert Museum and RIBA with their joint collections, gallery and information services[10]
- Exhibition and information institutions, centres for public engagement in architecture, e.g. The Architecture centre network[11]
- Regulatory and planning authorities[12]
- Heritage bodies with responsibility for historical and significant built environment artefacts, e.g. statutory bodies like English Heritage[13]
- Government departments responsible for social needs policy in areas like housing, e.g. the Communities and Local Government Department[14]
- Government departments responsible for industrial policy in sectors like construction and the creative industries, e.g. Department for Business Innovation and Skills (BIS)[15]

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[9] For a brief explanation of “Sheer Curation” see http://en.wikipedia.org/wiki/Digital_curation

[10] http://www.vam.ac.uk/collections/architecture/index.html

[11] http://www.architecturecentre.net/docs/about/about/

[12] http://www.planningportal.gov.uk/

[13] http://www.english-heritage.org.uk/

[14] http://www.communities.gov.uk/corporate/about/

- Bodies mediating professional training, registration, recognition and development in architecture e.g. Architects Registration Board[16]
- Architectural practices, firms and their representative bodies
- Architectural Research, Innovation, Education and Learning bodies, e.g. the Commission for Architecture and the Built Environment (CABE)[17]
- Higher Education Institutions departments of Architecture

2.2 Architecture in Higher Education

There are 46 schools of architecture in the UK with courses validated by the Royal Institute of British Architecture[18]. The institutional base for academic architectural research in the UK, as analysed by Jenkins, P., Forsyth, L., and Smith, H. (2004)[19], showed 13 architectural schools orientated to the built environment, 17 to the visual arts and 6 to social science/humanities. The total number [20] of architecture students is 13,778.

The overall size of the Teaching and Research base for architecture in higher Education can be gauged from the staff numbers found in Architecture Schools in the RIBA 2007/08 survey with 517 fulltime and 300 part-time teaching staff and 216 fulltime and 63 part-time support staff. The Research Assessment Exercise 2008 subject overview report for unit of assessment (UOE) 30 Architecture and the Built Environment[21] reports a headcount of 676 for research active staff (630.63 full-time equivalent). The UOE 64 History of Art,

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[15] http://www.berr.gov.uk/whatwedo/sectors/construction/index.html

[16] http://www.arb.org.uk/

[17] http://www.cabe.org.uk/about-cabe

[18] For a list see http://www.architecture.com/EducationAndCareers/Validation/Validatedcourses.aspx

[19] Jenkins, P., Forsyth, L., and Smith, H. (2004). Balancing Three Dimensions in Architectural Research: depth, breadth and length. An institutional analysis of research in architecture in the UK higher education sector, Edinburgh College of Art. http://www.scotmark.eca.ac.uk/reports/4.pdf

[20] Based on RIBA Education Statistics for 2007-2008.
http://www.architecture.com/EducationAndCareers/Validation/EducationStatistics.aspx

The RIBA Centre for Architectural Education gives an average staff size for schools "On average, each School has 13 full-time teaching staff, 8 part-time teaching staff (contract); plus 7 full-time and 2 part-time support staff" see page 15 of the 2007-2008 statistics.
http://www.architecture.com/Files/RIBAProfessionalServices/Education/Validation/2007/RIBA%20Education%20Statistics%202007-08.pdf

[21] RAE2008 subject overviews, http://www.rae.ac.uk/pubs/2009/ov/

Architecture and Design subject overview report[22] reports 30 institutional submissions with an average of 12 researchers per submissions.

The teaching and research base for architecture in the UK Higher Education Institutions (HEIs) may be described as relatively small.

2.3 Architecture as a profession, Architecture as a business

The modern architectural profession is controlled by contract law and professional regulation as well as the professional education required for legal registration[23] which is a condition of use of the protected title "Architect". Within the UK there are 32,221 registered architects[24] (as at 31/12/2007). Entry to the profession is controlled by the validation[25] of approved courses by the Royal Institute of British Architecture and the Architects Registration Board. Registration brings the benefit of being able to practise in a Europe wide market as a qualified architect offering professional services to clients and also the benefit of working under a professional code of conduct which requires Professional Indemnity Insurance (PII) to mitigate the risks of litigation.

The architecture industry in the UK is one of the smallest creative industries[26], employing 5% (38,000 people in 7,100 firms) of all the creative industry employees (based on 2005 figures) with a total turnover of 2.9 billion pounds. About 1000 firms account for 80% of the total industry turnover with the top 8 firms generating 20% of the total turnover.

In business terms digital working in architecture may best be understood in the context professional services supporting industry sectors like construction. In the Survey of UK Construction Professional Services (CPS) for 2005/06[27] the Construction Industry Council estimates that architecture as a CPS generated fee income to the tune of £3.3 billion. The total for all Professional Service firms is given as £13.9 billion (made up of Engineering services £3.9 billion, Management Services £1.7 billion, Surveying Services £2.3 billion,

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[22] RAE2008 subject overviews, http://www.rae.ac.uk/pubs/2009/ov/

[23] In the UK the Architects Registration Board http://www.arb.org.uk.

[24] http://www.arb.org.uk/news/annual-report-2007/arb-at-a-glance.shtml

[25] http://www.architecture.com/EducationAndCareers/Validation/UKvalidation.aspx

[26] The figures in the section are taken from "Analysis of Firm Level Growth in Creative Industries: a report prepared for DCMS. Frontier Economics, February 2008".

[27] "Survey of UK Construction Professional Services 2005/06". Construction Industry Council. This based on a survey with responses from 801 firms (response rate 6.2 per cent) from a sample size of 12,924 firms which was drawn from the Experian National Business Database, a commercial data source. See http://www.cic.org.uk/services/publicationsCIC.shtml#pss

Facilities Management and other £1.3 billion, Planning £1.4 billion). Most architectural firms are small with 5 or less staff. Only 1% of architecture firms (126 firms) employ 50 or more staff.

The architecture industry is predominantly a small to medium enterprise sector with a few very large firms. This SME structure has implications for how research may be supported as well as the capital investment level, available at practice level, for investment in innovation through ICT techniques and tools.

Construction Professional Services (CPS) firms, outside of architecture firms, may also offer architecture services. Significantly the multi-disciplinary firms provide over one half of the total architecture, engineering and facilities management (FM) services. That is because these tend to be the largest firms generating the majority of the fees. Over 48% of the fee income (£6.6 billion) is earned by multidisciplinary firms in the CPS sector.

2.4 Culture of Professional Practice

Regulation, compliance and intellectual property regimes are strong factors in shaping the practice of architecture; this provides the context for any communication of knowledge, including design specification, intended for contracted parties, or for clients, whether in analogue or digital formats. Architects work within a strong legal framework of contracts and the management of contingent liability is a requirement for the reputation, health and survival of a commercial practice.

The legal requirements governing the care of architects records vary with the jurisdiction[28] but defence against claims, including adjudication of disputes, is a key driver for professional maintenance of adequate records of work (electronic or paper). In the United Kingdom simple contracts have a period of six years during which a legal action can be started while contracts executed as a deed can have actions started for up to 12 years. The Construction Industry Council recommends “retain/archive key project documents for a period of no less than 17-20 years”[29]. There is also a requirement for permanent retention of some classes of business record (corporate records, agreements etc). Many professional architectural archivists would seek to keep paper records in parallel with electronic records[30]. Any digital

[28] For a brief account of requirements in different countries “Legal requirements for architects records” from AAE : Architecture archives Europe see http://archivesarchitecture.gaudi-programme.eu/fichiers/t_pdf/18/pdf_fichier_en_AAE_Legal_requirements_July_06.pdf

[29] Construction Industry Council “Liability briefing on e-Business” at http://www.cic.org.uk/activities/eBusP7.shtml

[30] For an example see advice in “Guidelines to managing architectural records” (Version 01, 31 December 2004) from AAE : Architecture archive Europe see http://archivesarchitecture.gaudi-programme.eu/fichiers/t_pdf/14/pdf_fichier_en_Prescriptions_en_anglais,_version_web01.pdf

curation treatment for architecture does need to take account of hybrid digital / analogue forms of working where documents, information and data may exist in parallel in digital and analogue versions.

2.5 Professional education & development

Architecture is a complex subject including all aspects of professional practice. Pedagogically the subject has a strong focus on practice and the use of multi-disciplinary working to support collaborative design and project delivery. In the architectural education required for entry to the profession, there is a body of knowledge which is acquired through "learning by doing" methods for instance through collaborative working in a design studio environment on design exercises or projects under the tutorage of more experienced designers. These learning methods support tacit and experiential learning which may not be easily captured in a codified professional knowledge base. The extensive industrial placement requirement included as part of qualifying as a professional architect also gives emphasis to a "knowing-by-doing"[31] approach to learning. In an industrial and professional practice context many of the issues an architect deals with are complex requiring integration of concepts, methods and techniques from the various disciplines involved in building design and built environment construction projects.

The concept of studio based working in design, and studio design project methods, is carried over to the online presence for many architectural courses[32] and also to concepts of virtual studio working[33] for online environments. Architectural Research is carried out with techniques and theoretical orientations adopted from many other disciplines[34]. As a consequence innovation in digital forms of working in architecture has been strongly evident as each generation of Information Communication Technology has developed.

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[31] For an account of "knowing-by-doing" in relation to overcoming barriers to learning in Architecture see Heylighen, A., Neuckermans, H., Casaer, M. & Dewulf, G. P. M. (2007). Building memories. Building Research & Information, 35 (1), 90-100. Retrieved April 13, 2009, from http://www.informaworld.com/10.1080/09613210600945369

[32] See the "Digital Studio" at the School of Architecture and Construction at the University of Greenwich http://digitalstudio.gre.ac.uk/ for one example of such a portal or website.

[33] For a fairly early example see "Virtual studios – the Luton experience" by Adrian Dobson. Habitat Issue2 (June 1996) at http://www.cebe.heacademy.ac.uk/learning/habitat/HABITAT2/luton.html

[34] See Moloney, J. (2000) Studio based research in architecture: the legacy and new horizons offered by digital technology. Working Papers in Art and Design 1
http://sitem.herts.ac.uk/artdes_research/papers/wpades/vol1/moloney1.html
for one view of the role of the studio design based methods in relation to the Architectural Research and the use of digital methods.

The study required to qualify as an architect takes about seven years combining five years in university education with a least two years of industry placement in paid employment (in order to achieve the required full RIBA Part 1, 2 and 3 exams).

The pedagogic approach[35] stresses a central role for professional requirements such as business management and factors relating to running a design practice as well the centrality of project working and creativity in formulating design briefs and possible solutions. The professional architect's role integrates, over disciplinary boundaries, the aesthetic, artistic, technical, scientific and economic aspects of forming and meeting a client brief through delivery of a product design under standard contractual terms. There is an emphasis on each candidate creating a portfolio of work to meet the requirements of RIBA and also of ongoing professional development.[36] The portfolio[37] may well be a hybrid of digital and analogue forms of documentation (including projects, plans, drawings, sketches, models and visualisations) and is likely to be built up and used by the architect, as their career progresses, to define a body of work demonstrating experience, skills, prowess and inspiration. There is a strong professional sense of ownership as well an education and practice based emphasis on collaborative and studio based methods of working. Architectural practices use the record of the firm's previous work in their bids for new commissions and in general promotion (for instance on the public practice web site). Industrial placement, as a route to entry and full qualification in the profession, ensures awareness of the imperative of competing and winning commissions in a commercial practice context.

After qualification the obligation for Continuing Professional Development is a formal requirement of RIBA chartered membership[38] with stress on continuous up-skilling to cope with change and development including that arising from new ICT techniques and tools.

2.6 Industrial context of Architecture

There are three broad points in relation to the form of digital working that has developed

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[35] See the criteria for validation of courses at http://www.architecture.com/EducationAndCareers/Validation/ValidationCriteria.aspx and also the Architecture subject benchmarks at http://www.qaa.ac.uk/academicinfrastructure/benchmark/honours/default.asp

[36] See RIBA's Professional Educational and development Resource (PEDR) website http://www.pedr.co.uk/

[37] Portfolios are commonly used as a means of assessment for admission to courses including further degrees and research; for an example specification of what is required see this University of Edinburgh example http://www.ace.ed.ac.uk/aad/admission/index.html#port for the MSc Advanced Architectural Design course.

[38] For detail of Continuing Professional Development obligations see http://www.architecture.com/EducationAndCareers/CPD/CPDAtTheRIBA.aspx

1. The use of commodity packaged based software tools (e.g. AutoCAD) has thrived in the SME environment.

2. The communication of specification and design information through a project management structure has become a dominant form of digital working over the architectural supply chain.

3. Historically the information in digital form has been duplicated by each party in the supply chain with each party owning their own digital assets and managing the liability and risks arising from delivery of contracted services. This reflects intellectual property rights in commercial property, including design information, and concern to manage any contingent liability arising in construction project with risk managed within a contractual framework.

3 Architectural Research: digital working and the disciplinary context

In the 21st century many digital methods of working are not limited to any one subject but are found over a complex continuum of disciplinarity. This is especially true of the kinds of research work which seek to generate knowledge and support transfer of techniques and apply results in a professional practice context.

The digital tools and methods that predominate are not specific to architecture but rather in a business context are commonly used in the whole of an industry supply chain e.g. construction industry use of CAD systems and packages (e.g. AutoCAD) by the various disciplines involved in building design and construction (such as architect, structural engineers, interior designers, electrical engineers, heating and ventilation engineers, fire engineers, mechanical engineers, quantity surveyors, etc). In an industrial context the sharing of information (including digital forms) is set within a project and contract based working environment which is managed and engineered to protect the various business interests while seeking to deliver to an agreed client brief over the whole gamut of the design, construction and management processes. The computer tools themselves may consist of separate applications each dedicated to a particular problem domain (for example, two-dimensional drawings, perspectives, engineering calculations, quantities, resources and cost planning models). The issues of common application tools or sharing standards and convention in the capture and communication of data have been the subject of long term industry and academic effort over decades (from at least the 1970s) as each generation of ICT has developed.

The goal of integrated knowledge sharing, for instance through product modelling standardisation in the building or construction domain, has not yet been realised in everyday practice. The factors which make this a complex problem are also relevant for any creation of a digital curation treatment that aims to enable the care of digital objects produced by the architecture profession. Many of the digital objects produced have a specific context within the processes of a design specialism (Architects, Structural, Civil or Service engineers, Constructors, Component and materials manufacturers) that can make sharing of information a challenge requiring higher levels of professional working and active cooperation.

Architecture, as a subject, displays a complex disciplinarity[39]. There is not a simple view of what constitutes architectural research work. There is a record of innovation through use of digital tools and methods as the use of ICT has developed. From a Digital Curation perspective the interest is in understanding how the products of this work, including digital assets, may be cared for in the course of the ongoing development of the architectural

[39] For the variety of methods and outputs of architectural research see Jane Rendell (2004). Architectural research and disciplinarity. arq: Architectural Research Quarterly, 8 , pp 141-147 http://dx.doi.org/10.1017/S135913550400017X

knowledge base and how the research objectives may be best supported by digital forms of working. This is especially the case where research outputs or products are available in digital form or where the research itself makes use of digital techniques and methods.

The complexity of architecture is reflected in the way that research work is carried out. Architecture, as a subject studied in the academic domain, uses research methods from natural science, social science, art and design, history and critical analysis. There can be an eclectic use of epistemological traditions as well as methods.

The nature of architecture research covers many of the types in any given research typology[40] e.g. Scholarly research, Basic research, Strategic research, Applied research, practice-led research. It is possible to argue that practice-led research is not a type of research but a way of undertaking research. However it is clearly a prominent form of research which as the Review Report for the AHRC[41] shows is part of the landscape of Art, Design, Architecture (ADA) research in the UK and internationally.

Architecture, including Architectural Research, is closely related to other fields such as design, technology, construction, engineering, planning, cultural, environmental and political context, practice/management/regulatory compliance issues (amongst others). The research problems often require inter-disciplinary collaboration given the complexity of the problem domain e.g. architecture research contributions in social and economic regeneration projects.

Architectural research projects encompass more than one type of research and may work with research questions and methods from a number of these related fields. In some cases working with different methodologies can be linked with subject areas e.g. technical and materials based research may follow a "scientific" method, architectural history or theory may follow a "social science" or a "humanities" methodology, architectural design research may follow a practice led research methodology related to "art and design". Each of these methodologies has, to an extent, its own scholarly tradition which may influence the form of research outcomes e.g. Science journal publication verses a Humanities scholarly book tradition or the kind of practice-led research which produces exhibition based forms of research output.

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[40] For an example typology see Boddington, Ann (2005) "Research Typologies in Architecture & Design". Presentation at "Architectural Research Future : a UK National Conference on Current and New Research Agendas 15 - 16 December 2005"
http://www.eca.ac.uk/archresearchconf/presentations/Anne%20Boddington_Research%20Typologies.pdf

For definitions of some types see Brown, B., Gough P., Rodis, J. (2004) "Types of Research in the Creative Arts and Design" http://artsresearch.brighton.ac.uk/links/practice-led/4_research.pdf

[41] Rust, C., Mottram, J., Till, J. (2007) "AHRC Research Review : Practice-Led Research in Art, Design and Architecture". Version 2. http://www.ahrc.ac.uk/About/Policy/Documents/Practice-Led_Review_Nov07.pdf

3.1 Function of Architectural Research

The function of architectural research ranges from knowledge search, specific project or product-based research and development, to pure and applied research including innovation and knowledge transfer. In a professional practice context there is a concentration of research activity on knowledge search around products as a normal part of providing design services.

Architectural research straddles both scholarship in the academic domain and industrial research and development for instance in the built environment domain. There is a dual focus between:

A. The process and technology aspects of buildings and spaces (including design, materials and components, construction management, tradition and precedents)

B. The built environment as an object or place (including design method as a creative process, form and purpose in buildings and spaces, cultural, social, environmental and historical aspects). Places, including buildings or built structures, and the uses and meaning of these for users and communities.

The second of these reflects an architecture that is more about a cultural product where the meaning of buildings and places for modern society is an important part of both the study and practice of the subject.

3.2 Context and nature of funded research

In architecture one kind of research work seeks to generate knowledge and support transfer of techniques and apply results in a professional practice context. The role of Higher Education Institutions in carrying out this research and in producing a skilled workforce of architects is a crucial one. The link between research outcomes, learning methods and introduction of new techniques in practice, including digital working methods, is especially close in architecture given the prerequisite requirements and route for entry to the profession.

The research and development funding that supports research within universities, research organisations and industry is mediated through established links with Government Departments, Research Councils, the European Union and industry. In the case of the construction sector the links with government are complex, covering many of the departments of government with many funding links difficult to trace.

3.2.1 Government funding of research useful to the Construction industry

In the report "Construction Matters. Ninth Report of Session 2007-08[42]" the House of Commons Business and Enterprise Committee found "Unlike most other developed countries the UK does not have a dedicated publicly funded research and innovation programme for its construction sector[43] ". The report identifies that "the usual commercial drivers that lead businesses to invest in R&D are either missing or very weak for a large part of the construction industry". In the absence of commercial drivers it is more difficult to make a business case supporting the resources needed for digital curation of research results (whether in higher education or industrial settings) through demonstrated benefits realisation.

In its written evidence the Department for Business, Enterprise and Regulatory Reform (BERR)[44] identified that there are no central statistics kept within Government or the Technology Strategy Board of research spending relating to construction. It is difficult to identify or track public funding for research and development supporting Professional Construction Services like Architecture.

In relation to the construction industry as a whole, BERR has identified a) limited investment in Research & Development by the construction sector b) poor knowledge transfer between the research base and industry. BERR says the majority of R&D is evident among UK design and consulting engineers and product manufactures and identifies the problem a being due to a "large, project-based and fragmented sector, comprised mainly of small firms requiring durable assets in a highly regulated environment".

3.2.2 Higher Education Research Funding

The Arts & Humanities Research Council describe the research landscape of the UK research base and give figures[45] for the size and sources of funding available for research. Architecture falls both within the Art / Design / Architecture (ADA) cognate subjects which could be regarded as humanities based and also with the Architecture / Engineering /

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[42] Great Britain. Parliament. House of Commons Business and Enterprise Committee. Construction Matters HC 127-I, Ninth Report of Session 2007-08 - Volume I: Report, Together with Formal Minutes http://www.parliament.the-stationery-office.com/pa/cm200708/cmselect/cmberr/127/12702.htm

[43] Paragraph 263

[44] Following government re-organisation (2009) the large part of the department responsibility is with the Department for Business, Innovation and Skills (BIS) see http://www.berr.gov.uk/aboutus/corporate/index.html

[45] For the description of the UK Research base see "Arts and Humanities Research Landscape". AHRC, 2009. This gives a breakdown in research funding by source (table 3, pg 22). http://www.ahrc.ac.uk/About/Policy/Documents/Landscape.pdf

Construction (AEC) cluster which may be funded on a non-humanities basis. The proportion of research grant (66%) coming to institutions as a result of the Research Assessment Exercise (Quality Related funding) is much higher for Arts and Humanities subjects, and the proportion of research council funding (14.7%) is much less than non-arts and humanities subjects.

In 2006/07 the OSI Research Council spend on Arts and Humanities was £45 million (from AHRC) with a further £15 million from other research councils (14.7% of total funding from research councils).

The public funding for research in Architecture and the Built Environment in the Research Assessment Exercise 2008 (RAE2008, Sub-panel H30[46]) over the period 2001 to 2007 is estimated at a total of 114 million pounds (approximately) for the period 2001-2007[47] growing from 8 million in 2001 to about 22 million in 2007.

The Engineering and Physical Sciences Research Council (EPSRC), in June 2009[48], classified 239 EPSRC current research grants (with a total value of £146,887,698) as having research activity (in whole or in part) with application in the construction sector (as defined by Standard Industrial Classification). Of these grants 28 were for a value of greater than one million pounds. Many of these grants relate to more than one industrial sector. Some grants are funding research infrastructure, such as doctorial training centres or research centres, e.g. The Innovative Construction Research Centre[49] (ICRC) at the University of Reading. Grants supporting infrastructure, like the funded Innovative Manufacturing Research Centres[50], provide for some continuity of funding allowing researchers to work on longer term research and develop relationships with industrial partners on a research programme rather than simply a single project basis.

Rust, C., Mottram, J., Till, J. (2007) in their AHRC review of practice-led research were able to analyse the research funding record showing for instance that in the period 1998 to 2006 there were 666 projects funded by the AHRC/AHRB (research council / research board)

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[46] See http://www.rae.ac.uk/pubs/2009/ov/

[47] As a comparison the RAE 2008 UoA 63 Art and Design subject overview report gives 110 million (approximately) as a research income for the period 2001-2007 with about 26 million won in OST/OSI research council peer-reviewed competitive bidding.

[48] See the EPSRC "Grants on the Web" facility for the updated information on grants issued by the research council. For a list relating to the construction sector see http://gow.epsrc.ac.uk/ChooseTTS.aspx?Mode=SECTOR&ItemId=6

[49] http://www.icrc-reading.org/

[50] For a list of current innovative manufacturing research centres see http://www.epsrc.ac.uk/ResearchFunding/Programmes/BetterExploitation/IMRCs/CurrentCentres.htm

covering areas that included the study and practice of Art, Design or Architecture. The total value of these projects was of the order of 28 million pounds with an average award value of 43,154 pounds. One way of measuring the likely level of research in architecture is to look at the measure of research outputs over a period. For instance in the period 1996 to 2005 Rust, C., Mottram, J., Till, J. (2007) found 81 Architecture PhDs were awarded in the United Kingdom.

The level of Higher Education research funding, and numbers of projects, is lower in architecture than science-based subjects where there is a clearer understanding of the research funders' principal responsibility for the public funding strategy. It is more difficult to estimate the research funding for architecture partly because the subject and profession cuts across many of the areas of responsibility of funders.

3.2.3 Cross sector context of architectural research

Translating research in subjects like architecture through practice, innovation and exploitation in complex institutional settings is a major challenge. Current efforts to meet this include the work of Technology Strategy Board (TSB), as a business-led executive non-departmental public body, in funding the "Modern Built Environment Knowledge Transfer Network"[51].

The sources of funding for architectural research are difficult to track across sectors. There is a lack of coordination between the various agencies supporting public spending on research and development. The Government has accepted that a "Chief Construction Officer" (CCO) role[52] at a senior level in government may be required to help foster innovation across the industry. A strategy of relying on the UK's National Platform for the Built Environment[53] to foster business-led research may be hampered by the level of funding available.

Conclusion:

Architectural Research requires a spectrum of digital curation approaches from which appropriate treatments can be selected to suit:

- the needs of the research methods used
- the problems studied
- the variety of kinds research products

[51] For the TSB funded knowledge transfer network see http://www.mbektn.co.uk .

[52] For government consultation on the CCO role see http://www.ogc.gov.uk/documents/CCO_discussion_document.pdf

[53] For one attempt to build an industry-led strategic research agenda for the United Kingdom construction sector see http://www.nationalplatform.org.uk/uksra.jsp

- the complexity of the organisational settings in which architects are educated, trained and employed in working with clients and fellow professionals
- the industrial structure of economic sectors, such as the creative industries and construction, including the strategy supporting research, development and innovation.

4 Digital working in Architecture: context and development

In contemporary architecture, design disciplines and construction, representations (which form the focus of many knowledge intensive areas of work) centre on visual and tangible materials such as plans, elevations and sections, models, sketches, photographs, slide shows, moving pictures and these may co-exist in both digital and analogue forms. Digital (e.g. CAD drawing) and analogue (e.g. paper plan) media are used together with a mutual feeding back of amendment and changes in the course of the normal lifecycle of design work. Digital working is assimilated to professional working but rather than replacement or displacement of material there is an ongoing evolution of possibilities in both analogue and digital artefacts.

4.1 Design activities in Architecture

A drawing is a product of the design process but does not describe the process of design or design methods. Initial attempts at computer based drawing (in Engineering Design and Architecture) adopted a low level representation of rendering lines as connected points on screen and plotter output. What was being represented in the computer was a drawing rather than the object (e.g. building) being designed. In early computer development representing a drawing was in itself an enormously computationally challenging activity to support interactively. Within the Architecture/Engineering/ Construction market the first dominant concept for commercial CAD products was an electronic drafting system realised using a geometric editor to produce paper drawing or plan outputs. The form of digital working both echoed manual drawing office procedures of working and amplified the throughput of paper based drawings that could be produced. It was new technology able to be assimilated into drawing office practice as a process of "rationalisation".

In considering the lessons from the first attempts to use computerised techniques, including Computer Aided Design (CAD), Aart Bijl considered that the "field of CAD requires theories of design that embrace human designers"[54]. In Architecture, drawing is recognised as a language for expressing whatever people have in mind and as a way of communicating. The focus is more on the design studio rather than the "drawing office". Simon Unwin[55] teases out the nature of drawing as a medium in Architecture:

- A medium for communicating (with colleagues, clients, builders etc), for specification and presentation

[54] Bijl, Aart (1987) "Making drawings talk: pictures in minds and machines". Computer Graphics Forum, Volume 6 , Issue 4 (Dec., 1987), p. 289 – 298. http://dx.doi.org/10.1111/j.1467-8659.1987.tb00557.x

[55] Unwin, Simon (2007) "Analysing architecture through drawing". Building Research & Information, Volume 35 Number 1, 2007, pp. 101-110. http://dx.doi.org/10.1080/09613210600879881

- A medium for designing (working things out, private play and reflection, generating and developing the design)
- A medium for analysis (acquiring knowledge and understanding), use of precedent

Drawing as architectural expression may be executed on many drawing surfaces (paper, computer screen, graphics tablet) and is comprehensive of freehand, sketched, diagrammatic, schematic or geometric forms.

4.2 How Architects design, how architects use computer techniques

In the development of digital working in architecture, computer techniques have been assimilated to support the predominance of visual representation as a means to embody knowledge. Visual representations are used to support the practice of generating, evolving and exchanging knowledge and in mediating multidisciplinary project and team working. Ethnographic work looking at design in architectural practices, for instance Ewenstein and Whyte (2007)[56], has highlighted the uncertainty, incompleteness, unknowns that are worked with in the design process. Sets of visual representations are used as a basis of the interaction between the architects and other professionals working on the project. The different experts comprising the design teams working on a project bring to bear differing views, competencies, and responsibilities but together are able to work through a wide range of uncertainties, ignorances, risks and yet-to-be determined aspects. The visual representations are themselves actively viewed, handled, updated and manipulated during discussion. For instance drawings or plans may have tracing paper placed over them and changes sketched on to the tracing paper as alternative options are considered.

The pattern of hybrid working, with analogue and digital forms, is observed in allied constructions professions such as civil engineering. Suchman (2000)[57] described the use of Computer-Aided Design (CAD) systems to support integration of analysis, 3D visualisations, flattened renditions as sections and plans. Suchman found extensive use of paper plans in consultations meetings with annotations made on the plans during the meeting. Computer based calculation and analysis were support by the engineer manually checking calculations on paper. The paper workings gave a clear visible trail or audit of calculation steps which could be seen and checked and rechecked at each stage and could be shown and checked

[56] Ewenstein, Boris. Whyte, Jennifer (2007). “Visual representations as ‘artefacts of knowing’”. Building Research & Information, Volume 35 Number 1, 2007, pp. 81 – 89. http://dx.doi.org/10.1080/09613210600950377

[57] Suchman, Lucy (2000). Embodied Practices of Engineering Work. Mind, Culture, and Activity, volume 7, issue 1, p. 4-18. http://www.informaworld.com/smpp/content~content=a785309362~db=all

with colleagues. To an extent the analysis was understood by the manual working out on paper.

In a design work context professional practices assimilate digital working through use of both digital and analogue artefacts, both at the screen and on paper, working with tacit as well as explicit knowledge, using techniques of collaboration and joint working.

Computers, through CAD systems, are used to support design at the latter stages. Conceptual or early stage design is typically manually transferred by an architect from sketches to a CAD tool. The early stage of design will often include the whole building, aesthetics, usage and functionality, design ideas and intention. Some research attempts to capture early design stages and produce an early design computer tool are reviewed by Kraft (2007)[58] who reports that no current existing CAD tools are able to provide adequate support for the conceptual design phase. Conceptual design information, including decisions about the organisational structure of the building, is not captured by the CAD tool. This is part of the human knowledge an architect works with and understands, often in the context of a design team.

4.3 Use made of computer based techniques

One approach to understanding the limitations and potential of actual computer use, both in architecture practices and also in the construction industry sector, is to look at surveys of the use made of Information Technology in Architecture and the construction sector. The focus is: what is done with computer based tools and information technology rather than on the vision of what could be or should be done.

Samuelson (2008)[59] in a 2007 survey finds that the focus is on systems that can support a business and not more advanced techniques that may transform the way a business works. The emphasis is on core business and needs. When asked where they are planning to increase their investment in IT systems, CAD is first for designers, portable equipment/mobile systems for contractors, electronic trade for the materials industry. When asked what motivates decisions on new IT investment survey responses highlighted the efficiency of work methods as most important driver ranking the desire to make administrative work more efficient as the most important reason. The survey finds that the importance of CAD and the increasing importance of Product models/BIM is marked for architects but has a lower priority for the construction sector as a whole.

[58] Kraft, Bodo, Nagl, Manfred (2007). "Visual knowledge specification for conceptual design: definition and tool support". Advanced Engineering Informatics, Volume 21, Issue 1, January 2007, pp. 67-83 http://dx.doi.org/10.1016/j.aei.2006.10.001

[59] Samuelson, Olle (2008) The IT-barometer – a decade's development of IT use in the Swedish construction sector, ITcon Vol. 13, pg. 1-19, http://www.itcon.org/2008/1

How are architects, and the other disciplines in building projects, actually using BIM systems? What is meant in practice by a BIM system?

Samuelson found 60% of architects used BIM software only for geometric data for 2D and 3D design. The Erabuild 2008 report and survey[60] of Nordic countries found that architects used manual drafting for 10% of design work, CAD for 70% of design with BIM used for over 20% of design work.

The Erabuild report makes the point that BIM can be seen as the next generation of CAD tools working with design objects while a more ambitious view is to see BIM as a system where all information regarding a building is fully integrated and accessible for all project participants. Full integration would include geometry, properties, specifications, extractions (drawings & views), quantity take-off, processes etc. In current practice most specifications, analysis and simulations are done independently of the BIM system. The initial approach may be that BIM will continue to be introduced as 3D CAD, not used to integrate all kinds of information, but used to support productivity gains with traditional ways of working.

The context for Building Information Modelling (BIM) methodology is project based, working with a digital building model forming a core repository (database) from which drawings, 3D models and sections, quantity estimations and simulations are derived. The intention is that the digital model then continues to be used and provides a basis for management of the building after handover to the client over the useful life of the building. Given the heterogeneous nature of the data held in the model, and the relatively short IT systems and software change cycles, validation will be required as the systems supporting the BIM are upgraded to ensure the integrity of information over time. Forms of digital curation will be needed to care, and ensure the effectiveness, of the BIM system both over the BIM's own lifecycle and over the lifecycle of the data it contains and transacts.

4.4 How designers share design information

Demian and Fruchter (2006)[61] found in an ethnographic study that knowledge reuse in the architecture / engineering / construction industry is mediated by social networks. One approach to reuse of design data is that knowledge could (or should) be captured and stored in an external repository to that all employees could share and reuse. A second approach is to recognise that the better sources of knowledge are the people in the

[60] Kiviniemi, A., Tarandi, V., Karlshöj, J., Bell, H. and Karud, O. J. (2008), Erabuild-report: Review of the Development and Implementation of IFC-compatible BIM, Sintef, Norway http://akseli.tekes.fi/opencms/opencms/OhjelmaPortaali/ohjelmat/Sara/fi/Dokumenttiarkisto/Viestinta_ja_aktivointi/Loppuraportti_aineistot_2007/Erabuild_BIM_Final_Report_January_2008.pdf

[61]

company who often posses a great deal of tacit and contextual knowledge that is difficult to encode and capture. One issue is how computer based systems can support this second type of knowledge reuse or support social knowledge networks. The findings of the study were that AEC practitioners prefer to ask colleagues who have worked on similar projects or have faced similar problems. Where the design information being reused is externally encoded (e.g. in an old blueprint) the social knowledge network is used to help identify, locate, retrieve and understand the information. Where external repositories of information were used the social network was often used to help locate information in the repository. The human expert could contextualise the design knowledge in terms of the project in which it was originally used and so help with understanding the appropriateness of reusing the information for the current design task.

Architectural practices appropriate information technology techniques to the multimodal nature of design work. That is, in design, use is made of multiple information systems, multiple representations, multiple people, multiple artefacts; contradictions, dissonance and inconsistency are worked through in the design process. The nature of project working in the construction industry adds to the variety of information technology systems used.

4.5 Nature of Construction projects

Construction projects are collaborative inter-firm organisations where collective problem solving across the different professional roles and sub-systems of work is not rigidly codified even though duties and responsibilities may be contractually defined. The Erabuild 2008 report finds that project materials are maintained manually and that firms do not yet see integrated building models as a way to reuse data, information and knowledge gained during project participation. The CIRIA (Construction Industry Research and Information Association) Project Information Management and Archiving draft scoping study (RP724)[62] provides a survey view of how project information is supported, including manual methods, by a number of larger multi-disciplinary companies:

[62] Project Information Management and Archiving Draft Scoping study. CIRIA, 2006.

Source: summarised from CIRIA. Project Information Management and Archiving draft scoping study

Many companies tend to use the same information managements systems on all projects (subject to scale of project) but the use of the systems as extranets is not always enforceable. The project team requirements, or the client, determine use and only a few companies enforce use.

Quality management systems are often in place but these do not necessarily cover all aspects of information management.

Most companies seek to keep information for legal reasons. Information is reused but the degree of reuse depends on the kind of project with more specialised projects supporting more reuse.

Retention periods of documents are used. There was uncertainty about the selection of documents and the format in which electronic documents should be stored. There was a lack of policy for review of documents once stored. Use of CD and DVD to store documents did not include a policy to check for readability of information over time.

End of project reviews were carried out. Projects generate much paper copy which was used on projects and retained although it may also be scanned. The main issue was sorting hard copy at the end of a project to decide how it should be organised and boxed up. Electronic information is increasing with some companies using a document management system or extranet. Companies also use the files structure on a server as the means to store documents. The problem was the lack of metadata and documents being filed in the "wrong" place. The lack of version control meant copies of documents could be worked on locally but the relationship to the original copy lost, with a resulting loss of control over multiple versions of documents.

The use of email systems includes use of public or project folders to store messages but without consistent filing. Attachments are stored with emails leading to problems with multiple versions of documents.

Most companies had a system of recording expertise of staff based around a skills database of CV but the problem was keeping this updated. Best practice notes published on the intranet were found to be useful.

The team leader or project manager was the person responsible for management of project documents. Some of the companies had a company archivist or librarian looking after company specific information.

In regard to IT systems the pattern was that members had multiple information management system in place, based on: files on servers, document management systems, collaboration systems, internally developed systems. New systems were introduced but the policy of migration of information from older systems was variable.

4.6 Future use of Digital Curation approaches to support a Strategic Research Agenda

The National Platform for the Built Environment, which is industry owned and led, has developed a Strategic Research Agenda[63]. Based on the European Construction Technology Platform[64] this has prioritised three areas: Reduced resource consumption; a client driven, knowledge based construction process; ICT and automation.

The National Platform's ICT and Automation Scoping Study Report identified five key research topics:

- Collaborative prototyping to define and deliver client requirements
- Efficient, seamless sharing of information across the built environment stakeholders
- Ability to interact with real-time information regardless of physical location or time zone
- Mass adoption and application of off-site manufacturing, automation and mechanisation processes and systems
- Well trained, well qualified workforce able to use the latest best practice technologies

Within the roadmap for sharing information the use of digital models and distributed management of data models through BIM systems is highlighted as a short term (5 year) objective supported by standards for data and metadata exchange. The interoperability of software systems used at all stages of the buildings life (design, construction, operation) is a medium term (5-15 year) objective. The use of ontologies and open ICT standards to support a semantic web based communication throughout the supply chain is characterised as a medium term objective.

For an analysis of various alternative roadmaps see appendix B of the VTT report by Paiho, S. et al. (2008)[65].

The various roadmaps for built environment research indicate the desire to use digital technologies as enablers of the business processes essential to a reconfigured construction sector. However the digital assets used and produced have themselves a much shorter useful life than the built environment they are helping to create. The digital object and assets, including models, will require active curation if they are to survive and contribute value over the life cycle of structures in the built environment. This includes preservation of digital assets for the purposes of the project and any digital models used to support the

[63] For details of the process of forming the SRA see http://www.nationalplatform.org.uk/uksra.jsp

[64] The Strategic Research Agenda for the European Construction Sector: achieving a sustainable and competitive construction sector by 2030 see http://cordis.europa.eu/technology-platforms/pdf/ectp2.pdf

[65] Paiho, S.; Ahlqvist, T. Piira, K.; Porkka, J. Siltanen, P. Tuomaala, P. Kiviniemi, A. (2008). Roadmap for ICT-based Opportunities in the Development of the Built Environment. VTT, Espoo. 58 p. + app. 33 p. http://www.vtt.fi/inf/pdf/tiedotteet/2008/T2444.pdf

future use and care of the building or structure. The decisions in selecting and appraising which digital assets to maintain will be investment decisions. The business models to support the level of care required, taking account of the material interests of the parties involved in built environment decisions, are not yet envisaged.

Recommendation 1: that the Digital Curation Centre consider approaching the National Platform for the Built Environment to explore promotion of work to identify the digital curation standards for data and metadata exchange required to support digital models, including appropriate consideration of provenance requirements and processes such as preservation analysis.

5 Infrastructure and digital curation in architecture

In this section we will look at an example of a research project to get an indication of how architecture departments currently generate, use and provide for research data and review efforts to create repositories and infrastructure supporting architectural research. The development of a UK higher education research data service[66] may include provision for support of the research data and digital assets generated in architecture departments.

5.1 Example project

The AHRC funded project "Inflecting Space: Correlating the attributes of voice with the character of urban space" carried out by the University of Edinburgh Department of Architecture gives an example of use of generated research data. The project ran for just over a year (ending December 2006) and looked specifically at correlation between the spatial configuration of distinct urban environments (public and commercial places) and the voice modulated through public address systems, audio signage and mobile phones.

The methods used included field recording and observation, sound studies in artificial sonic environments, interview of designers who had set up sound installations for public consumption, focus groups, sound archive research and historical analysis including use of oral histories. Places studied included Waterloo Station, London. The aim was to better understand the relationship between place and voice and in particular as processed through digital media. Objectives included: to help research into better audio signage for public spaces, design of better public spaces attuned to the characteristics of voice in the digital age, apply techniques of cataloguing, browsing and retrieving vocal sounds on the basis of inflection.

The outputs included a digital exhibition in a public venue, conference presentations, and a refereed journal article reporting the outcomes of the project, a chapter in a book, and six digital installations. The electronic resources produced included over 400 sound samples of the voice in everyday situations with metadata and corresponding automated production of visual representations as 'inflection diagrams' or 'melographs' to test visual browsing of sound and automated pattern matching. In addition 200 further environmental sounds, interview recordings, vocal studies and visual images were produced.

This relatively small project (research grant of 51781 pounds) generated a variety of types of digital assets. The assets are stored in a Unix file system directory structure. The assets are accessed and used through a web site developed using the ColdFusion application development language. Access is controlled (by authentication of users).

[66] For an interesting approach, scoping the possible forms of a national service, see the summary of the UK Research Data Service study, "The data imperative : managing the UK's research data for future use" UKRDS, 2009. http://www.ukrds.ac.uk/UKRDS%20Report%20web.pdf

The infrastructure used to care for the digital assets of the project is under the control of the department and is supported by the computing officers in the School (Arts, Culture and Environment) to which the department belongs. The infrastructure was developed as part of a project (funded by Edinburgh University) to create an e-learning repository in the department for the MSc courses in Design and Digital Media and the MSc in Sound Design[67]. This is a working tool for the students (over 50 per year) and staff with access controlled using the University wide authentication system and also supporting publication of content through web sites to the public. The digital assets from research projects may be reused for learning purposes.

A number of key points emerge from a curation infrastructure policy point of view

- The infrastructure (including repository) supports both learning resources and research data uses
- The system is local and is under departmental control with local computer officer support but integrated into the wider university computer services system (e.g. common federated user authentication services)
- The system was developed by the department with the needs of the department, its researchers and students in mind focusing on visual and design related requirements for authoring and publishing contents to design and project groups as well as supporting public access for a subset of resources through authored web sites.
- The current system does not support federation of search and discovery services either over learning resources or research data digital assets.
- The assets are under the Intellectual Property Rights control of the University.

The UK Research Data Service is proposed to operate under a "cooperative service model" as an enabling framework to work with existing (and future) stakeholders. As well as highlighting development of data management plans by researchers the aim is to exploit existing facilities giving guidance on which repositories provide useful research data. This implies a federated approach to search and resource discovery over distributed repositories.

Recommendation 2: that in preparation for a federated approach to networked search and resource discovery the Digital Curation Centre should collaborate with relevant Higher Education Institutions and Subject Departments, Research Councils and architectural professional bodies such Royal Institute of British Architects (RIBA) to influence guidance to institutions, researchers and practitioners on planning and managing the curation of digital assets produced in architecture and that this is carried forward in guidance for Continuing Professional Development programs.

[67] For an example of the range digital assets produced in MSc design level courses see http://ddm.caad.ed.ac.uk/WIP08/

5.2 Current landscape and development of repositories for Architecture

A pilot web interface to a subject-based cross-repository search tool for resource discovery in engineering is available at http://www.engineering.ac.uk. It is limited in its content with little engineering research data. There is no UK equivalent for architecture. The PerX project[68], which created the pilot engineering resource discovery service, carried out an analysis of the landscape for engineering digital repositories[69] in November 2005. No substantial subject based repositories were found to exist for engineering. Overall PerX found the level of "digital repository provision specifically for the engineering community appears to be relatively low". The same finding could be repeated for Architecture. However this depends on the definition, or how broadly you define, a repository. For instance, PerX excluded 'closed access' commercially produced repositories which do not allow free searching.

The JISC Repositories and Preservation Programme (April 2006 – March 2009) funded the development of a number of higher education digital repositories. Amongst these was the Lincoln Repository of Learning Materials (LILOREM) located in the School of Architecture. The ambition was to develop a Virtual Studio through establishing an open access institutional repository capable of handling material generated by the students of the Lincoln School of Architecture and also research materials. The intention was that the model of development could be used for other disciplines especially those that make extensive use of multimedia.

In practice[70] the LILOREM project found the visual emphasis and practice based approach was not adequately supported by the text based publishing model used by the available institutional repository software systems. In particular the publishing workflow of the eprints software was of little interest to students or researchers in architecture. It took a student 17 distinct steps to negotiate the text based user interface and upload one piece of design work. As well as the absence of a graphically appealing interface the demands to enter standardised metadata were seen as rigid and a burden unlikely to gain user support.

Although in architecture a Virtual Studio can be thought of as a multimedia repository the Virtual Studio is closer to a system designed for interaction with learning objects rather than simply a repository for dissemination of research results. The distinction is in the learn-by-doing, design by making and practice led research methodologies which support a reflective

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[68] http://www.icbl.hw.ac.uk/perx/index.htm

[69] http://www.icbl.hw.ac.uk/perx/analysis.htm

[70] Earl, Andy and O'coill, Carl and Winn, Joss (2008) Virtual Studio: a Digital Repository in Architectural Education. In: Online Repositories in Architecture Conference, 20-21 September 2008, Venice. http://eprints.lincoln.ac.uk/1617/

use of multimedia as a resource, including disaggregation and re-purposing, with the aim of gaining a collaborative design experience.

Given the strong role for practice led research methodologies design based disciplines may benefit from a common treatment, including common repository infrastructure and services, for learning and research based assets and data. The point is to consider repository services meeting different kinds of use (research use, learning use) rather than conceive of distinct repositories needed for each kind of data, each kind of research or learning product.

5.3 Ingest to repositories

Some of the issues with uploading material to repositories, highlighted by the LILOREM project, have been dealt with in the SWORD[71] (Simple Web-service Offering Repository Deposit) Project. This provides an interactive drag and drop method of populating repositories. For instance there is an officeSWORD plugin for uploading Office documents to a repository directly from within the Office applications using the SWORD protocol.

5.4 Curation services integrated with workflow

It would be useful to extend this SWORD approach to the more common applications used in Architecture and Design. Commercial software packages and tools used for digital manipulation, such as the Adobe CS4 suite of programs, support the editing and creation of metadata as part of the workflow of working with digital assets for instance with Adobe media manager Bridge CS4[72]. Also available is direct capture of metadata from instruments[73] e.g. EXIF metadata used to capture data from a digital camera, embedded in an image file. These techniques are based on the use of Adobe Extensible Metadata Platform (XMP) which is a proprietary standard but supports third party development through an XMP Toolkit SDK[74] including use of custom information panels within Adobe products.

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[71] For details of the SWORD lightweight protocol see http://swordapp.org/. For an illustration of SWORD in use see SWORD: Cutting through the Red Tape to Populate Learning Materials Repositories by Sarah Currier. http://www.elearning.ac.uk/features/sword

[72] For a video on creating metadata using Adobe Bridge software, working with images see http://www.peachpit.com/podcasts/episode.aspx?e=a6cbae1e-bcdb-48ec-84dd-3fcec369e483

[73] For a video demonstrating use of metadata with video editing see http://www.studiodaily.com/main/video/Metadata-in-Adobe-CS4_10128.html

[74] XMP developer site at http://www.adobe.com/devnet/xmp/

In order to support a Virtual Studio concept it would be best if the user were aware of the "repository" aspect, including curation services, through the user interface of the applications and environment that were worked with most of the time. This is especially the case with software producers like Adobe who have adopted a workflow approach to the management of digital assets. Repository services would benefit from being embedded in the workflow systems used by practitioners.

Such an approach would give effect to a form of sheer curation where curation is integrated into work flow of those creating and managing data and other digital assets. This would allow some aspects of curation, e.g. metadata capture, to be built into the training and standards introduced as part of learning how to use the digital environment.

5.5 Federated cross domain, cross institution search and resource discovery

The JISC MIDESS (Management of Images in a Distributed Environment with Shared Services)[75] provided a "lessons learnt" approach to the difficulties of linking 3 areas:

- development of institutional repositories in Higher Education
- management of image and multimedia resources to provide access for researchers and learners supporting multiple purposes and content reuse within education
- use of the Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH) to support searching across domains and institutional boundaries.

One of the aims of the MIDESS project was to share content between partners (from different institutions) based on use of OAI-PMH, effectively aggregating content retrieval over distributed repositories. In architecture there are many commercial online sources of design information, including visual resources, available. These are used to support research and learning but each online source requires separate access and use without clear aggregation or sharing of content, or of standards. The MIDESS project showed how difficult it can be to combine commercial and open source repository solutions. In practice MIDESS found that, although is widely used, there were many problems in implementing OAI-PMH for resource discovery. Although the protocol supports sharing of digital objects (MIDESS looked at using METS, Metadata Encoding & Transmission Standard as the transport mechanism) this was not widely supported in the available repository platforms.

5.6 Metadata ensuring common approaches

Multimedia repositories may use a wider range of metadata[76] schemes, reflecting the many purposes of different multimedia collections, such as Metadata Object Description Schema

[75] http://www.jisc.ac.uk/whatwedo/programmes/digitalrepositories2005/midess.aspx

(MODS), Encoded Archival Description (EAD), IEEE Learning Object Metadata (LOM), etc. In order to support inter-operability there needs to be mapping between schemes. For instance, in the case of e-learning approaches, including virtual learning environments (VLE), the IMS metadata specification[77] might offer appropriate description for learning description. Initiatives like RAMLET[78] seek to map the different resources description to they can be commonly dealt with.

5.7 Common federated search and resource discovery for Architecture

Using a wider definition of repositories the European MACE[79] (Metadata for Architectural Contents) project has established a database[80] describing more than 200 architectural repositories of content useful for architectural education and research. The scope of what is covered includes architectural archives (digital and digitised paper archives), E-learning platforms, material databases covering products and technologies used in architecture and construction, Project databases including architects' websites, visual collections as sources for architectural student and practitioners.

The problem with so many repositories of useful information is that common access is not available. Each repository has its own intended audience and search mechanism with no coordination of content between repositories and yet each is potentially useful in supporting the broad range of materials useful for education and research in architecture and design. The materials are formed as complex digital objects with textual and visual media including images, videos, descriptions of projects, illustrations of architectural ideas and often delivered via a web interface. The digital objects themselves may be used for a research purpose or for a learning purpose.

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[76] For background on metadata and multimedia see JISC Digital Media at http://www.jiscdigitalmedia.ac.uk/crossmedia/advice/putting-things-in-order-links-to-metadata-schemas-and-related-standards/

[77] For the specification see http://www.imsproject.org/metadata/ ; for a best practice guide see http://www.imsglobal.org/metadata/mdv1p3pd/imsmd_bestv1p3pd.html

[78] For RAMLET see http://ieeeltsc.wordpress.com/working-groups/ramlet/; For details on content packaging standards see http://www.ukoln.ac.uk/repositories/digirep/index/Content_Packaging_Standards

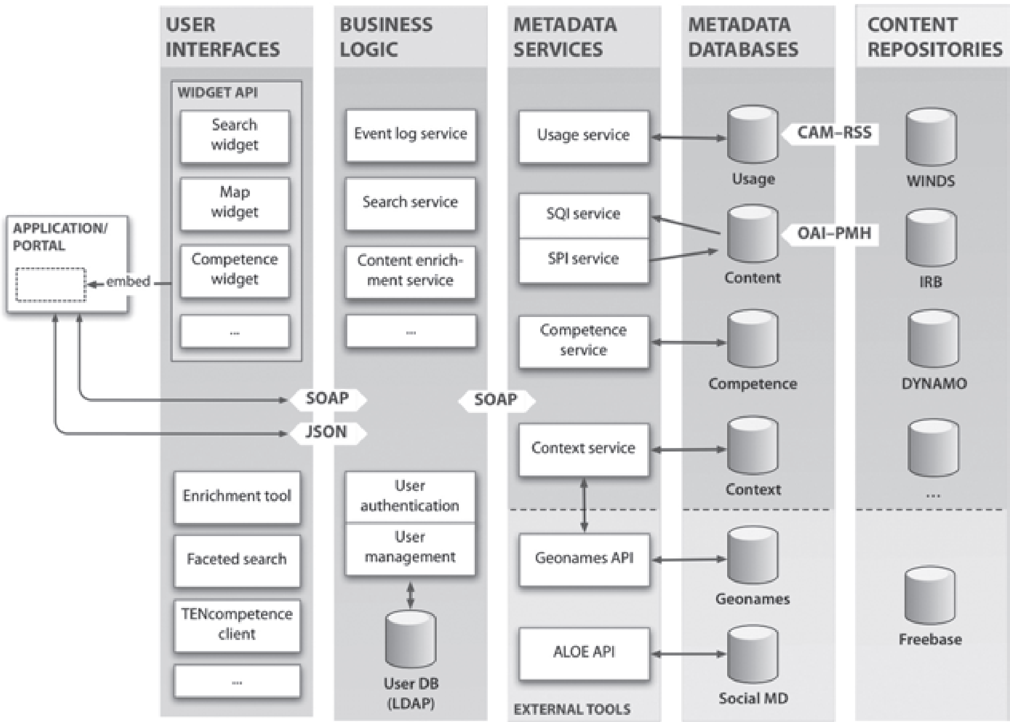
[79] The MACE project started in September 2006 financed by the European Commission within the eContentplus program. The basic idea is to make digital architectural content in Europe more recognisable, accessible and selectable through the ability to select learning objects, using a shared ontology, from the distributed web-connected repositories. http://portal.mace-project.eu/

[80] Boeykens, Stefan. Neuckermans, Herman. A database of architectural repositories: criteria for selection and evaluation. http://www.mace-project.eu/images/macebook/mace_25b.pdf

The MACE project has demonstrated a method to create a federated architectural learning repositories infrastructure.

Figure 1 MACE technical infrastructure

source: "Browsing architecture: metadata and beyond". IRB Stuttgart (Germany), ISBN: 978-3-8167-7770-0, September 2008. P. 320



The technical infrastructure supports searching over all the content repositories. The mechanism is based on gathering metadata from connected repositories and storing it in a central metadata repository. The digital objects remain within each distinct repository. The semantic interoperability between repositories (each uses its own metadata scheme) is provided by use of the MACE application profile [81] which is based on the IEEE Learning Object Metadata (LOM) Standard[82].

In integrating access to content from Learning Object Repositories the MACE services adds value through enrichment with different types of metadata as well as classification structures supporting structured search and browsing through visual interfaces. The indexing system is based on four types of metadata:

- Usage and Social metadata; how, by whom and in which context a learning resource has been used. The Contextualised Attention Metadata (CAM) schema describes activities in relation to the learning objects and the users.

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[81] MACE application profile version 3.0 (May2008) available at http://www.mace-project.eu/media/deliverables/WP7/D7_5/Annex%20A%20-%20MACE%20application%20profile%20V3_0.pdf

[82] For a brief description of this type of data model see http://en.wikipedia.org/wiki/Learning_object_metadata

Activities captured include login/logout, View including learning objects viewed, Search including keys and repositories used, Ratings covering which learning objects have been rated by the user.
The CAM store is used to support personalised ranking metrics and what is most sought (zeitgeist) services. The data gathered in CAM is available for harvesting through OAI-PHM. Web 2.0 based collaboration tools systems supported include user creation and sharing of annotations, ratings, tags and portfolio pages. This is supported by incorporating the ALOE (Adaptable Learning Object Environment) project[83] within the MACE environment

- Competence metadata; a catalogue of the competences to which each learning object is held to be relevant to according to the domain and underlying pedagogical system. For instance an Architectural Competency Classification based on the European Qualifications Framework. MACE provides an open application programming interface (API) to integrate services based on a competence catalogue into end user tagging applications. Uses include structuring curricula, courses of study and personal development plans.
- Contextual metadata; capture of the context where real world object are referred to (places, buildings, built structures, towns etc.). For example name of building, location, dates of construction, surroundings and place where the building (built structure) is situated. Includes mapping/location GPS services. The indexing or metadata applied to the real world object (building or project) can be inherited by the associated learning objects, without duplication or restatement, as a form of content enrichment.
- Content and domain metadata; Descriptive metadata relevant to the architectural domain harvested from connected learning repositories, enhanced by 1) architectural experts (MACE editorial group) and 2) by the community in architectural education (students, teachers etc.) through their own tagging and comments.

Browsing (and searching) is supported by the MACE classification schema which is faceted and based on Uniclass[84], ISO12006[85], the AAT Getty Vocabulary[86] and Ci/SfB[87]. The design strategy for the interface to MACE service is based on “widgets” or application components which can be integrated into existing portals. This allows content providers to use MACE

[83] ALOE project see http://aloe-project.de/. For details of the Web 2.0 design principles see http://ftp.informatik.rwth-aachen.de/Publications/CEUR-WS/Vol-280/p10.pdf

[84]The Unified Classification for the Construction Industry see http://en.wikipedia.org/wiki/UniClass

[85] ISO 12006 "Building construction", an international standard for organising information about construction works see http://en.wikipedia.org/wiki/ISO_12006

[86] Art & Architecture Thesaurus ® (AAT) et al, see http://www.getty.edu/research/conducting_research/vocabularies/aat/about.html .

[87] CI/SfB stands for Construction Index/Samarbetskommitten for Byggnadsfragor. It is typically used for organising product information. For an example of such a service see http://www.ascinfo.co.uk/9/category/category13_9.html. The RIBA Product Selector is based around use of CI/SfB see http://www.thenbs.com/products/ribaProductSelector/index.asp

services, through embedding widgets, while gathering traffic through their own web sites. There is also a MACE portal allowing mediated access to the distributed member repositories and also personalised information management for users including social networking.

5.8 Limits of MACE project approach

The MACE project is exemplary in providing a proof of concept for common access to distributed architectural education and research resource repositories.

- Reliability. In practice when you use the portal not all the resource are available at any one time. This may relate to the availability of service from the distributed repositories which run under their own management. There may be no common service level agreement. For a production environment the robustness of the services would need to be shown and measured in an ongoing manner.
- Burden / Benefit. MACE offers sophistication in creation of metadata for the architecture domain. There is obviously a cost of effort in making indexing systems consistent. The amount of effort expended at indexing/description stage verses the effectiveness and effort at retrieval stage needs to be balanced. It would be useful to measure the relative merits of the different approaches e.g. social tagging verses expert indexing and gauge the balance of effort[88].
- Business model. The technical ability to search distributed learning repositories through harvesting metadata and common presentation services needs to be supported by the business reasons for a content provider or repository to take part. The MACE system leaves the control and delivery of the digital objects/content with the originating repository and this has the benefit of distributing the intellectual property rights issues to the repositories' owner/managers. Different users can have different rights of access according to the policy of the particular repository. As a content enhancement service, or in digital curation terms a service adding value through curation, what is the funding model that would most effectively produce benefits (for content providers, for users, for the Architectural Community, for society) in operating MACE services?

5.9 Example of the possible benefit of common repository services for Research and Learning resources

In examining a MACE like approach for architectural research data it is worth considering Usage and Social metadata; how, by whom and in which context a resource has been used.

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[88] The JISC Enhanced Tagging for Discovery (EnTag) project investigated the combination and comparison of controlled and folksonomy approaches see http://www.ukoln.ac.uk/projects/enhanced-tagging/.

Usage and Social metadata can be extremely valuable. Researchers and designers are interested in sharing data but would like to know who is using the data and for what purpose. Where data and digital assets are shared under data sharing agreements being able to track who has viewed or used the given assets and for what purpose is likely to be an important way of returning value to the research data content originator.

5.10 UK approach to institutional repositories

The 2006 JISC funded report "Linking UK Repositories[89]" sets out technical and organisational models for user services across institutional and other digital repositories. To an extent the MACE project fits within the framework of the Linking UK Repositories study, but has developed an approach for a subject domain (Architecture) and a particular community (Architectural Education community) for subject specific repositories at an international level rather than institutional repositories at a national level.

What repositories (and content) are there in architecture and design departments in the UK Higher Education system that could be linked using "Linking UK Repositories" approach?

UK architecture and design departments have many repositories to which they may contribute content. In a UK University context repositories include:

- Those used for Research assessment such as the RAE 2008 exercise
- The University's institutional repository
- Virtual Learning Environments (VLE) such as the commercial Blackboard products, e.g. WebCT Vista 8, or the open source moodle[90]
- Content Management Systems such as DRUPAL
- Online virtual environments such as Second Life[91]

As Boeykens and Neukermans point out in their review[92] of learning environments and CMS many of these systems are not best suited to the visual methods of working required for

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[89] Swan, A., Awre, C. (2006) Linking UK Repositories: Technical & Organisational Models to Support User-Oriented Services Across Institutional & Other Digital Repositories. http://www.jisc.ac.uk/publications/documents/linkingukrepositoriesreport.aspx

[90] For an example of the use of Moodle in a teaching and design studio context see Martens, B. and Achten, H. (2008)"Do you Moodle?: experiences with a Virtual Learning Environment" in: Architecture in Computro, 26th eCAADe Conference Proceedings, Antwerpen (Belgium), Sep. 2008, pp. 153-160. "http://alexandria.tue.nl/openaccess/Metis219449.pdf

[91] For ideas and examples of Virtual Learning environments in Architecture and Design see the blog http://archsl.wordpress.com/

design and studio work. Challenges include integration of any developed departmental design portal with the default larger University business systems such as Blackboard and SAP.

Architectural and design departments may still feel the need to develop repository systems, with web interfaces, which better fit their methods of working. From a national service perspective of searching and resource discovery for architectural research data (or learning resources) the key issue is to what extent standards like OAI-PMH can be required for repositories.

The benefits to architecture, at a subject and departmental level, of taking part as a contributor of content to a national data service would need to be set out. Advocacy of service development along the lines of a MACE-like model would be able to point the benefits of content enrichment, common search retrieval services, visibility for the institutional content originator, measurement of the use made of the contributed assets.

Recommendation 3: that JISC invite European MACE project representatives to an appropriate JISC repository forum to explore the development and future of the services developed in the MACE project including lessons learned and consideration of the possible extension beyond the architecture subject domain.

5.11 Industry and new forms of digital working in Architecture

In working with graphical and visual tools, such as CAD systems, designers are building a model which provides for multiple views of underlying architectural representations[93]. Digital environments are expected to augment the modelling repertories available to the architect enabling explorations of new possibilities in the concept, forms and construction of buildings.

In a professional design context, building models consisting only of geometric information would not adequately capture what the architect and other disciplines are doing in collaborating on the making of a design and assuring the delivery of a building through stages of construction. Drawings are one form of the production information required; also included are requirements, specifications, bills of quantity or schedules of work, communications and records of instruction.

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[92] Boeykens, S. Neuckermans, H. (2009) "Content Management Systems versus Learning Environments". CAADRIA edition:2009 Yunlin, Taiwan, 22-25 April 2009. https://lirias.kuleuven.be/handle/123456789/221858?mode=simple

[93] For a discussion on Architectural Representations see Koutamanis, Alexander. Halin, Giles. Kvan, Thomas. (2007) Indexing and retrieval of visual design representations. http://hal.archives-ouvertes.fr/docs/00/26/77/28/PDF/ecaade2007-layout-beta-paper_148.pdf

A number of the major software suppliers are offering proprietary products to support the creation of computer interpretable information models. These are intended to support the various design professionals working on construction projects (architectural design, structural design, design of electrical and other services). These Building Information Model (BIM) products are intended to integrate the information required by the multiple collaborating partners in a construction project (architects, engineers, consultants, contractors, clients, building & facility managers, owners and end-users) through use of an ordered series of building models or a shared single building model. The aim is to support sharing of model data; for instance the architect's geometric model is linked to structural engineer's model and to the mechanical engineer's model. The advantage is consistency and checking for clashes in the various aspects of building design with a decreased risk of re-working being required as problems emerge at each stage of construction.

With a history of the use of proprietary software tools, such as CAD systems, the AEC (Architecture/Engineering/Construction) sector has problems with the inter-operability of digital assets with data created in one software application not always easily made available or shared with another application from another supplier (or even with an earlier version of the software from the same supplier).

The market place in which CAD systems developed is a proprietary one. The major packages used to create the CAD information are commercial applications, with private methods and algorithms, storing information in proprietary file formats. Much of data sharing revolves around using compatible file formats to permit export and import from different applications according to the interfaces provided by each proprietary application.

The industry has tried to manage these inter-operability problems through standards such as the "AEC (UK) CAD Standard for Drawing Management"[94] which extends procedures supporting information exchange based on paper documents[95] to sharing data through exchange of computer files. This recommends a policy for data transfer be established in each project with procedures such as:

1. Define and agree what data is to be transferred: Is it the digital drawing which is to be exchanged or is it the CAD models?

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[94] AEC (UK) Drawing Management Handbook v2.4
http://aecuk.files.wordpress.com/2009/05/aecukdrawingmanagementhandbook-v2-4.pdf

[95] The sharing of CAD-information between the participants in construction projects has traditionally been through plotted paper drawings. The need to exchange CAD data in digital form has given rise to a number of CAD standards. These include the conventions required to support manual and intellectual organisation, coding and also naming of the CAD files. Many of these standardisation efforts seek to codify existing practices developed in different national markets and companies.

2. Define the key stages for drawing issue and the frequency of intermediate information exchange: limit the frequency to manage the benefit against the overhead of frequent changes
3. Agree the distribution media: paper, CD, email, ftp, extranet
4. Agree file formats: agree a common format for exchange e.g. dwg ensuring all parties have the software of a stated and known version to correctly interpret and the data.
5. Establish a method of recording all issues and receipts of digital data: drawing registers and Issue sheets should apply to CAD model file exchanges
6. Trial data exchange: set up and trial data exchanges before finalising the exchange strategy.

The advantage of this approach is that a negotiated agreement by the parties to a project is more likely to be implemented appropriately with adjustments according to the scale and complexity of the project and the experience and resources of the partners.

The introduction of ICT to the construction industry has been used to amplify the procedures and style of working followed in manual document based information systems. Codes of practice like Construction Project Information (CPIC) Production Information Code[96] describe file management for small practices or small projects as "a filing cabinet based approach to IT" with data files stored in folders and sub-folders on a networked server file system. The result is a hybrid information system where analogue forms such as paper based drawings are complemented by use of CAD as an electronic drafting system.

To an extent this model of working is flexible allowing the retention of hard copy documentation for auditing and record purposes. Drawings, as printed documents, may be confirmed as final with the architect's mark or signature; these drawings may be retained for the architectural companies project archive beyond the end of the project.

In construction projects, which involve collaboration with multiple parties, the IT used is dominated by stand-alone application packages with a lack of software integration. There is no standard platform for information exchange per se. Document based data exchange, through exchange of files using standard and agreed versions of proprietary file formats like DXF, allows the use web based project management systems[97]. These "Project Extranets" or "Project Webs" provide graphical interfaces and a degree of underlying electronic

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[96] Construction Project Information Committee (2003) "Production information: a code of procedure for the construction industry" at http://www.productioninformation.org/final/contents.asp

[97] For background and case studies see Alshawi, M. Ingirige, B. (2003). "Web-enable project management: an emerging paradigm in construction". Automation in Construction, Volume 12, Issue 4, July 2003, Pages 349-364. http://dx.doi.org/10.1016/S0926-5805(03)00003-7 . For a survey of EDM systems in construction see Bjork, Bo-Christer. (2003). "Electronic Document Management in Construction: research issues and results". ITcon Volume 8, pp. 105-117. http://www.itcon.org/2003/9 .

document management as a basis for collaborative working and build on the common use of emails and attachment of documents as a means of exchanging information. They may use the underlying functionality of groupware products like Microsoft's Exchange and SharePoint products or IBM's Lotus Notes and Lotus Domino.

5.12 Curation role and repository infrastructure

In the use of a file system as a repository for digital information the curation processes and mechanisms required to support the responsibility for longer term access and use of the digital assets for a given designated community of users are left to manual procedures. Such procedures include naming of files, placing in a directory structure, coding of content, and migration of content by manually exporting/importing between file formats through proprietary interfaces.

Much of the automation of curation services required to support preservation of proprietary forms like CAD files is still at the research stage. For instance there is a Registry/Repository of Representation Information for Engineering[98] (RRoRIfE), established as part of a research project, which provides for the management of information loss in the migration between versions of CAD files (a least loss route in migration). However there is no established public service that supports this kind of migration/preservation in a production environment.

European projects such as CASPAR[99] (Cultural, Artistic and Scienti**f**ic knowledge **f**or Preservation, Access and Retrieval) have designed automation workflows[100] to support preservation analysis and are trialling these in test bed environments for Science data, Cultural Heritage, etc. This approach has the advantage of being standards based within the OAIS reference model[101] (ISO:14721:2003). However this is not yet at the stage of being implemented as a production service.

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[98] Ball, A., Ding, L., Patel, M., (2008) Towards a Curation and Preservation Architecture for CAD Engineering Models. Presentation at iPRES 2008 (British Library Conference Centre, 29-30 Sept. 2008). http://www.bl.uk/ipres2008/presentations_day1/17_Ball.pdf

[99] CASPAR - an Integrated Project co-financed by the European Union within the Sixth Framework Programme. For an outline of the work of the project see the CASPAR booklet 2nd edition, Available at http://www.casparpreserves.eu/publications/comm_materials/material/cas_booklet_iied.pdf.
For an introduction to the project see Giaretta, D. (2007). The CASPAR Approach to Digital Preservation. International Journal of Digital Curation, 2(1). http://www.ijdc.net/index.php/ijdc/article/view/29/32

[100] For CASPAR workflow overview see http://www.casparpreserves.eu/caspar_workflow.html

[101] For introduction and background on OAIS see http://www.ukoln.ac.uk/repositories/digirep/index/OAIS

Without an institutional structure and environment which supports an automation approach to curation services, including preservation, it will be difficult for practitioners, either academic architecture researchers or architects in design practices, to provide for longer term survival of digital assets except on an ad hoc basis according to local conditions and resources.

There is a role for curation organisations, such as the Digital Curation Centre, in support of infrastructure initiatives like the UK Research Data Service, through engagement with subject-based communities such as Architecture Departments in Higher Education Institutions

- to provide information on appropriate examples of known best practice for care of digital assets

- provide advice on the appropriate automation support of curation methods and in future establishment of repository services

- support the architectural departments' efforts in providing professional training for architects which embed care of digital objects in the normal methods used by architects in working in a digital environment.

There is a further requirement for curation-based research and service organisations to influence the development of the more domain specific digital environments, like Building Information Model (BIM) approaches in Architecture and Construction, to ensure standards based approaches to curation processes (such as repository ingest and preservation action) are provided for.

5.13 Curation and Building Information Model (BIM) approaches

An alternative to the use of proprietary file formats, with various model representations, for exchange of CAD model data between the multiple partners is to use a standard or neutral data model supporting interoperability between proprietary tools. This approach is associated with the concept of a Building Information Model (BIM) as shared building model holding information which is added to from the first stages of building design, through to construction, and throughout the building's useful life to the eventual demolition of the building. The BIM is regarded as a digital assets base, a standard digital information repository of building and systems design, of use to Architecture, Engineering, Construction and Facilities Management, with multiple parties contributing and accessing data throughout the buildings life. The introduction of this type of BIM involves re-engineering of the business processes across the AEC (Architecture / Engineering / Construction) sector. It is motivated by the use of ICT as a tool for transformational change rather than as an amplifier of existing methods of working.

The major effort for this inter-operable framework has been with buildingSMART International[102], bSI, (formally known as International Alliance for Interoperability) in producing the Industry Foundation Classes (IFC). The IFC data model supports the concept of collecting all the data of a building model in a shared representation.

There are two methods of sharing information using IFC

- Export and import through a data file containing model data representation. This follows the traditional industry file exchange practices. The STEP format (STEP-XML[103]) is intended to be open and neutral so that proprietary CAD vendors have the option of implementing interfaces to IFC in their commercial application software products . The format is text based (XML). An earlier non XML but text based STEP-file format[104] is also available.
- Through a database system that can accept, transact and store all data objects that comply with IFC and therefore act a IFC model server

Commercial vendors may certify their software as IFC compliant, supporting import/export, according to the version of IFC supported.[105]

Although the IFC has developed as a open standard data model over a longer period (from 1995) the development of certified IFC interfaces by the vendors of the leading CAD products has not resulted in a guaranteed ability to transfer CAD models between proprietary applications. The end users (e.g. professionals working on the design and construction of a building) need to check the results of transferring data, using IFC, between applications and cannot simply trust information will be accurately transferred. Pazlar (2008)[106] reviews the literature documenting the CAD data exchange problems arising in the use of IFC and also reports on experimental trial conversions using the simpler case of the architectural domain and geometric information. Pazlar found that the trial conversion testing could not be automated since the Globally Unique ID (GUID) used to identify objects

[102] http://www.buildingsmart.com/introduction buildingSMART® International Alliance for Interoperability.

[103] ISO 10303-28:2007 "Industrial automation systems and integration -- Product data representation and exchange -- Part 28: Implementation methods: XML representations of EXPRESS schemas and data, using XML schemas".

[104] ISO 10303-21:2002 "Industrial automation systems and integration -- Product data representation and exchange -- Part 21: Implementation methods: Clear text encoding of the exchange structure".

[105] See http://www.ifcwiki.org/index.php/Commercial_Software for a list of commercial software supporting IFC. For free, sometimes open source, software see http://www.ifcwiki.org/index.php/Free_Software .

[106] Pazlar, T. Turk, Z. (2008) "Interoperability in practice: geometric data exchance using the IFC standard", ITcon Vol. 13, Special Issue Case studies of BIM use , pp. 362-380. http://www.itcon.org/2008/24

was changed by some of the vendor application interfaces. Therefore a manual first stage of analysis and comparison of the results of conversion was made.

The Erabuild 2008 report[107] "Review of the Development and Implementation of IFC compatible BIM" summarises the limitations of file based exchange for BIM systems, including:

- Partial exchange is not supported. A whole project or building in IFC format is large and exchanging the whole model is not efficient given that only a small part of the model may have changed.
- File exchange methods do not support version control.
- The software certification process for IFC is insufficient to ensure dependable software and interfaces in proprietary applications limiting the use in real world projects

One advantage of use of a machine readable modelling language, rather than a file format, is the ability to support data transaction-based exchange of information objects through a model server rather than a document based file format import/export exchange. The concept of IFC model server, with the IFC data model implemented as a database, is intended to support applications directly exchanging data with the model server.

Currently, as reported by Jorgensen (2008)[108] there is no widely-accepted standard for the functionalities that a server should support or for which features should be offered. What is possible with current model servers is a simple level of use allowing publication of CAD models which allow whole models to be uploaded and downloaded on demand by authorised users. More complex use in selecting model objects, visualisation, analysis, reporting is not currently adequately supported. Merging models, and objects into models, to produce a single consistent model is not well-supported. The import/export interfaces are an obstacle to the use of model servers in construction projects. There is a need to provide for appropriate curation services, such as migration and preservation analysis, as part of the model server infrastructure.

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[107] Kiviniemi, A., Tarandi, V., Karlshöj, J., Bell, H. and Karud, O. J. (2008), Erabuild-report: Review of the Development and Implementation of IFC-compatible BIM, Sintef, Norway http://akseli.tekes.fi/opencms/opencms/OhjelmaPortaali/ohjelmat/Sara/fi/Dokumenttiarkisto/Viestinta_ja_aktivointi/Loppuraportti_aineistot_2007/Erabuild_BIM_Final_Report_January_2008.pdf

[108] Jørgensen, K. A., Skauge J., Christiansson P., Svidt K., Sørensen K. B., Mitchell J. (2008) "Use of IFC Model Servers: Modelling Collaboration Possibilities in Practice". Aalborg University, Aarhus School of Architecture, and University of New South Wales. May 2008. (60 pp.) http://it.civil.aau.dk/it/reports/2008_Ifc_model_server.pdf.

5.14 Future research and development of BIM

One approach to developing the use of IFC and model servers further is to develop a testbed as a method to involve the commercial vendors in market led standards development. The Open Geospatial Consortium, with buildingSMART, used the AECOO (Architecture, Engineering, Construction, Owner and Operator) testbed[109] to develop service interfaces using IFC. The concept is to develop alternatives to file-based exchange of data based on BIM-centric messaging between domains using a services architecture supporting registries, search, access, query, retrieval and security in a distributed environment. Vendor application packages would "talk" to BIM systems as repositories enabling a controlled level of sharing or "publication" of model data.

In the context of file-based exchange of CAD data Patel, Ball and Ding[110] (2008) develop a model for a repository service to manage the loss of information that is known to occur in migration of CAD models between file formats. The Registry/Repository of Representation Information for Engineering (RRoRIfE) is based on an ontology derived form of a superset of properties supported by a sample of CAD formats. Using XML schema each format is mapped against the particular properties it supports and for each format conversion a software application package is able to perform a record is scored for capability (none, poor, fair, good). The purpose of this tool, in curation terms, is preservation planning. The tool is able to generate possible migration pathways between file formats providing a least loss of significant properties route.

From a digital curation perspective the development of BIM infrastructure needs to take into account preservation planning. Given the long term survival required of a BIM (over the lifetime of a building) each time model data is added, or the software used to support the BIM is changed, there needs to be a measure of the degree to which the integrity of the BIM is maintained. In addition the provenance of the information held in the BIM needs to be clearly managed so that any conflict detected in future can be tracked back to a change point to allow possible resolution of integrity problems. A registry service, along the lines of RRoRIfe, would be a possible line of development for model server based exchanges of data extending from the curation treatment for file format import/export exchange developed by Patel, Ball and Ding. The development of the registry would take advantage from two buildingSMART component technologies:

[109]For background on the testbed process see http://www.opengeospatial.org/projects/initiatives/aecoo; For the objectives see presentation by Louise Hecht at The IDM/MVD/IFD Workshop, Washington April 8 2008. http://nbims.opengeospatial.org/files/?artifact_id=1512

[110] Patel, M., Ball, A., Ding, L. (2008) Strategies for the Curation of CAD Engineering Models. International Journal of Digital Curation, 4(1). http://www.ijdc.net/index.php/ijdc/article/view/104

- The role of IFD[111] (International Framework for Dictionaries) as an open library where concepts and terms are semantically defined and given a unique identification in identifying what information is being shared;
- The role of an IDM[112] (Information Delivery Manual) and MVD (Model View Definition) processes in specifying which information is to be exchanged in each type exchange scenario and how this maps to IFC (which information to share when)

Conclusions:

Both in Higher Education architectural research and in commercial architectural practice extensive use is made of file system-based methods as repositories for research and design data. Automation of curation processes as part of repository services is needed to encourage and support architectural research and design practitioners and to reduce the burden and ensure appropriate longer term survival of digital assets.

The current infrastructure in the AEC industry based on proprietary CAD systems and geometric models leads to the creation of digital objects (CAD Models) which lack information to support their use as assets beyond the context in which they were created. Workflows relying on manual migration of CAD data by file based import/export through application interfaces requires checking and validation to ensure management of information loss.

The BuildingSMART BIM approach introduces the possibility of higher level semantic information being coded with the CAD Model permitting a richer development of repository infrastructures supporting controlled sharing of models and model elements. In practice this is still a developing research area and it the uptake for such system in the industry may be longer term.

Domains such Architectural Education support of the use of CAD Models, with other contextual materials, as learning objects through federated services supporting enrichment of Metadata has been demonstrated in EU research projects like MACE (Metadata for Architectural Contents in Europe) based on an infrastructure of distributed repositories. Design disciplines may benefit from common repository services for research data and learning materials.

[111] For the background and development of IFD as a buildingSMART component see http://www.ifd-library.org/

[112] For details on the Information Delivery Manual see http://www.iai.no/idm/

6 Curation approaches for Architecture: factors, approach and treatment

Pragmatically it would be useful to describe a common approach to digital curation covering Architectural Education, Architectural Research and Architectural Practice. In order to enter the profession architects progress through academic, educational and commercial organisational settings gaining experience and knowledge of working methods. These methods (including practice-led research and 'learning by doing' approaches to the acquisition of tacit knowledge and design studio working) are additional to the professional knowledge base codified in the curriculum of courses and in the formal requirements for registration. Although the infrastructure and purposes may be different in academic, public and commercial organisational settings, the working methods adopted by architects develop and are applied across organisational settings.

For any curation treatment the scale of organisation is an important factor in managing the burden of effort and cost. Architectural firms are predominantly small to medium sized businesses enterprises. In the United Kingdom University based architectural departments are themselves comparatively small supporting a relatively small research base.

The Digital Curation Centre provides a source of coordinating advice on the care of digital assets supporting research, record and professional practice. The digital curation treatment appropriate will vary across organisations[113] as each have their own mandates, responsibilities and purposes. However use of common approaches to digital curation techniques will bring benefit to whole sectors, such as Higher Education, where the current use of digital working does produce digital assets, such as research data, that may be appropriately shared and exploited for joint benefit.

In a design disciplines context, the proliferating use of digital tools provides one link from design research and learning to innovation and practice. One measure of maturity in a given sector, or in professional practice, is the degree to which there is an infrastructure that helps manages the burden and cost of the care of digital assets as against the value and benefit to be obtained in current and future exploitation of digital resources. Introduction of extensive use of digital working without adequate curation of digital assets is both a risk to professional working and also represents a loss of the opportunities to be gained in exploiting intellectual capital.

[113] See section 2 organisational setting; organisations include content originating bodies such as Architectural Firms, Schools of Architecture, policy and collecting bodies, including government and government funded bodies, with responsibility covering Architecture and survival of an architectural record.

6.1 Digital Curation treatment appropriate to the practitioner's working methods

In introducing any requirements for curation there is a need to reflect how architects and architectural researchers currently use digital methods, with the resources and infrastructure available in a given organisational setting, to meet needs in research, education and professional practice.

A major function for digital objects is to act as a record of digital work that can be used for ongoing design work or shared/kept as the product of a design stage. Given the hybrid nature of much of work in architecture, for instance the product of a digital CAD drawing may be a printed series of plans shared with partners through a paper medium, the policies adopted for care of records[114] need to provide for both analogue (e.g. paper) and digital forms.

Any systems providing for records management or archival record would be expected to have policy for both analogue and digital records. Much of the policy would be common (e.g. common systems of project organisation such as project codes). For example the basic metadata needed to organise project photographs may need to include project codes, photographer's name, captions, dates, copyright holder information and this would apply to digital and traditional negative/print photographs.

6.2 Curation: capturing the context

For academic research, learning environments and also in professional practice any given digital object is best understood as an asset in the context of a particular design or research project. The project description, either as tacit or explicit knowledge, is an essential part of understanding the intended use of the digital object as a drawing, specification, instruction, communication etc. Most architectural projects are executed in architectural project phases and this provides a context for the management of digital objects and project documentation.

architectural project phase[115]

- Pre-design phase
- Preliminary design phase
- Final design phase
- Construction documents phase

[114] For an example of policies covering paper and digital records see the "Guidelines to managing architectural records" produced under the GAUDI program. http://www.gaudi-programme.eu/en/productions/bdd/event/20/

[115] For a description of architectural project stages see "A Guide to the Archival Care of Architectural Records 19th-20th centuries. Paris. International Council on Archives, 2000." http://www.ica.org/en/node/30170

- Bid documents and submissions
- Construction phase
- Acceptance and Handover phase

6.3 Example of a curation tool (ontology) for capturing context

The MIT Libraries FACADE project[116] in looking at requirements for curating architectural 3D CAD models found that the context of a Project Information Model (PIM) was required to ensure the use of the particular 3D CAD model to a designated community such as future researchers, design professionals, historians.

The idea of a PIM is that the entire architecture project (with assets such as initial sketches, 2D CAD drawings, 3D CAD and BIM models, images and other media files, client and public presentations, correspondence...) provides the context in which the meaning and use made of a 3D CAD model can be understood.

The FACADE project has created the Project Information Model ontology[117] so that each Digital Object as a file (e.g. 3D CAD model) is assigned five properties:

- Project Phase
- Building Zone/System
- Architectural/Engineering Discipline (e.g. architectural, mechanical, structural...)
- Document type (e.g. presentation, drawing, communication)
- File Format (e.g. AutoCAD, CATIA, Word, PDF...)

Within a small firm, or internal to a research or design team, much of what is captured in the FACADE Project Information Model may be held as tacit knowledge. The individual people working on the design are intimate with the materials and progress of the project and hold the context for the design in their mind and as a shared communication between team members. Much of the social interaction of design studio working involves the handling and re-working of artefacts with a heeding and re-affirming of design context as a shared meaning between participants.

There are industry standards supporting the coding and capture information to support sharing of assets between parties in design and construction projects[118]. However the actual

[116] For a description of the FACADE project see http://facade.mit.edu/

[117] For the published details of the FACADE project Project Information Model Ontology see http://libstaff.mit.edu/facade/index.php/Public:Ontology

[118] For an example of industry based standards supporting sharing of information see the AEC (UK) Standards Committee publications such as "AEC (UK) Cad Standard for basic layer naming : a unified CAD standard for the Architectural, Engineering and Construction industry in the UK" version 2.4 http://aecuk.files.wordpress.com/2009/05/aecukbasiclayernaminghandbook-v2-4.pdf

conventions used for coding may vary between projects (agreed by partners for the duration of a project) often as a variation from a published standard. For commercial projects of any scale there will a large number and variety of work artefacts such as presentations, reports, communications, instructions, specifications, project management plans and schedules, images. The FACADE project found these amounted to tens of thousands of artefacts for commercial projects with in many cases the digital form of these artefacts not accompanied by metadata or tags. The file system directory structure containing the digital files was a poor indicator of the relationship between artefacts.

6.4 The need for repositories of digital assets

In architecture design and research projects, the digital objects created and worked with are stored as files often using proprietary file formats. Workflows are supported by sharing access to files in project groups and by copying files to project partners. Much of this is done manually, perhaps using the conventions of the file directory tree structure, file naming and file access permission to enable group sharing, or using attachments of files to emails to deliver to partners. Most intranet and web based project extranet systems represent an extension of file based working.

Advantages of file based working include:

- User control: Control of naming, directory placement, and sharing through file access permissions can be exercised by the person creating or working on the digital object. This suits the needs of sole practitioners, small firms and research groups without access to dedicated support staff. Manual systems, perhaps based on paper filing rules, may be used as the basis to support digital working (including telling, showing and training by doing). All the proprietary software tools used support file based working.
- Scalable through computer support staff: The facilities required to support this kind of working are available at the level of the operating system, often through a graphical user interface, that comes with personal computers. Small scale organisations, such as sole practice architectural design firms, can apply file based working in using personal computers. File based techniques are extensible to server based computer system supporting workgroups at research group or department level which may be supported by system administration staff working in a computer support role.
- Information security, recovery of work: The association of digital object persistence with the existence of files allows provision for information security of digital information through low level administration of backup systems either by the user, on an ad hoc basis to off line media, or by support staff through some form of automated backup schedule.

Disadvantages and challenges of file based working include:

- The context of a file located in a directory structure may be lost when a file is moved or copied to a new directory or computer system. The placement of a file in a directory structure may not be reliable. Over time inconsistency of file placement in the directory structure is likely to grow in an ad hoc manner.

- Files may be duplicated and then individually edited without record or clarity as to the user intention to create a new digital object or a later version of the same digital object.
- Information on the software environment required to ensure the integrity and authenticity of digital objects on access may not be fully derived from identifying the file characteristics such as ownerships, permissions or identification of a particular proprietary format used. Migration of digital objects between software environments, or between file format versions and types, may result in information loss.

From a curation perspective the file system is being used as a repository for digital objects (as files) to support digital working. A repository might be implemented as a form of file system store, a database or digital asset management system, or networked based storage resource broker (e.g. offering data grid services).

6.5 Advantage of purpose designed repository systems; networked repository services

Purpose-designed repository systems for digital objects, such as Fedora[119], offer specific functionality for instance allowing the contents of a repository to be exposed and discoverable using standards such as the Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH). This allows a freedom in abstracting digital objects through their significant properties, without constraint of the computer file system conventions. This is the basis of content enrichment, through for instance enhanced metadata, by services such as those on the model of the MACE project[120]

6.5.1 Benefits to a sector of standards based repository services

The use of standards in such purpose-designed repository systems supports interoperability and federation across individual repositories to provide networked based repository services. On the scale of a sector, such as Higher Education, it is the nature of the repository services for a domain such as architecture or design disciplines which require to be specified. The aim is that architectural researchers create content through their own familiar tasks, employing processes and tools commonly used in their professional domain. Repository services are required to underlie the flow of work undertaken by designers and architectural researchers without distracting from the given design or research task in hand. One approach would be to build these types of repository services over a national data

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[119] For details of Fedora see http://www.fedora-commons.org/. The FACADE project explores the use of the DSpace repository system for archiving Digital CAD models.

[120] See for an example service the MACE visual project browser at http://portal.mace-project.eu/ProjectSearch

fabric service such as that offered by the Australian Research Collaboration Service.[121] The digital repository infrastructure for The UK Higher Education community is a developing area.[122]

Recommendation 4: that curation advocacy organisations, such as the Digital Curation Centre, take every opportunity to set out their view of the curation services required to support a federated cross institutional resource and discovery service for networked repository services covering specific subject domains, such as architecture in the UK Higher Education sector, in light of the developing digital repository infrastructure. That this should be done in alignment with the appropriate JISC programs and any initiatives, such as the United Kingdom Research Data Service, supporting national services for the care and exploitation of digital assets including research data. That this advocacy work be coordinated both with appropriate European Funded initiatives and with the UK bodies representing the designated subject community

6.6 Curation infrastructure for private, collaborative and public domains

In an architectural research context, or a professional design practice context, the majority of digital assets may remain private to the creator, research team or owning institution (e.g. an architectural firm). It may be only a specifically selected subset that is used as the basis for collaboration with partners or as the basis for the public presentation of design results. Assets will be made available to partners usually within the framework of an agreed purpose or joint project (using a tacit or explicit agreement). In a commercial or competitive context the design methods, or other research methods, may be regarded as a private intellectual property. The information rights associated with digital assets do need to be supported in the infrastructure of repository services. This would require support in any national research information data service so as to enable curation over private, collaborative and public domains.

Andrew Treloar and Cathrine Harboe-Ree (2008)[123] highlight a curation continuum approach which gives an analysis of the different domains over which data

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[121] For details of the ARC data fabric see http://www.arcs.org.au/products-services/data-services/arcs-data-fabric-start-here. The Australian National Data Service objectives include "Transform collections of Australian research data into a cohesive network of research repositories".

[122] For an indication of the current UK developments see Heery, R (2009). Digital Repositories Roadmap Review: towards a vision for research and learning in 2013. http://www.jisc.ac.uk/whatwedo/themes/informationenvironment/reproadmaprev.aspx

[123] Treloar, A. and Harboe-Ree, C. (2008). Data Management and the curation continuum: how the Monash experience is informing repository relationships. Proceedings of VALA 2008, Melbourne, February 2008. http://www.valaconf.org.au/vala2008/papers2008/111_Treloar_Final.pdf

stores/repositories might be expected to function. In terms of architectural research and design projects these are:

6.6.1 Private Research / Design domain

This is the core design or research project team. This may equate to the team in a single architecture firm or a project team in a multi-disciplinary practice. Many of the ideas and digital assets worked on will remain private to the team, especially in early stage designs. It may be that access needs to be tightly controlled or restricted in order to ensure free development of the work and also the firms/teams/designers ownership of its own intellectual capital including design ideas. Artefacts may be produced and used in analogue and digital forms (e.g. prototyping may be based on physical models and digital models) .

6.6.2 Collaboration or Shared Research / Design domain

The designers work with partners outside of the core team with other architectural disciplines, e.g. structural engineers. Partners may be formally recognised in a contract as part of the architectural project (or research project). Partners may have an informal relationship based on peer working with the team in a company or academic environment.

Collaboration with colleagues may involve work and consultation across institutional boundaries, including use of social and professional networks.

Some of the work products and artefacts, including digital assets, will be shared at the various design stages as a basis of getting input and information to complete an architectural projects phase (e.g. moving from preliminary design phase to final design phase may need quantity and costing information).

Work, including delivering results, with a client or funder will usually have a special status where sharing and consultation may be part of the design process or included in the delivery of a contracted service. This will be carefully controlled in contracted situation to manage expectations, customer/sponsor/client relations, closure on any design brief or research agreement, signoff of delivered results/product.

6.6.3 Publication or Public Research / Design domain

Presentations of work for public viewing or sharing. The attribution/citation of work is important. In architecture the basis of the presentation is often on a whole project or building basis. Focus is on results and significance. The quality of the visual element of the presentation is often very important in representing the work. In addition research results and design information may be made available to meet requirements of planning and regulatory authorities as well as an evidence base supporting the professional knowledge and research record. The motivation includes supporting reputation building and professional recognition and the use of this in winning new work including design and research projects.

In moving between the boundaries of the different domain digital objects travel to meet new audiences and potential uses. Curation is required at the boundaries of domains.

The boundary between the **Private Research / Design domain** and the **Collaboration or Shared Research / Design domain** requires curation in the sense that digital objects will selected and may be migrated, assigned access controls, with any metadata required to enable collaboration checked and augmented. Normally there will an explicit or implicit authority (architect or team leader) required to move assets for a private to a shared domain. With manual file based sharing (e.g. attachment of assets to an email) provision for integrity and authentication of the digital resource depends the on interaction, checking and trust between communicating parties including negotiated resolution of anomalies.

6.7 Compliance requirements and regulation of appropriate access to digital assets

In architectural projects the context for sharing information is the contract under which the parties work to deliver constructions or designs. In architectural or design research projects, for instance where commercial exploitation may be a possible outcome, there is also a need to exercise appropriate care in managing information covering ethical, legal and regulatory requirements. Ownership of information normally confers rights and legal obligations. Information and data is shared under a combination of explicit and formal agreements, professional terms and industry common working practices. Information systems supporting sharing and reuse of digital assets need to take account of the background agreement to share, the material interest of the parties, and the rights and conditions of use of the information. Much of this care is exercised by human monitoring to ensure that contingent liability (say in case of legal dispute) is managed.

As automation and digital working increases the possibilities of sharing information, including data, there is a need for support of agreements and policy enforcement through automation and repository infrastructure services. As information or data travels between domains and project phases the information sharing agreements need to travel with the data as part of the curation service that provides for appropriate access. Requirements (e.g. level of metadata) will vary as the digital assets travel through the domains (private, collaboration or shared, publication or public).   There needs to be a level of trustworthiness in the information shared. The position is complex in the case of digital analytical objects, such as modelling systems, where the information assimilated may have various ownerships and conditions of use. Curation systems for tracking provenance of digital assets will need automation support to help discover and resolve rights conflicts in any information assimilated to analytical digital objects, for instance Building Information Models.

The Consequence project[124] reflects one approach to applying automated methods to support data sharing agreements, including conflicts between agreements. The general scenario is that managers (principals) draft and sign data-sharing agreements containing policies which are to be enforced when data (information) is accessed and used (shared). The agreements are held in a form that is amenable to computer interpretation including automation of actions according to policy conditions. The aim is to provide a high degree of assurance on how digital assets are handled after having been made available under agreement. The objective is support of appropriate sharing within a secure and trusted digital environment providing policy based information rights management at use.

Recommendation 5: that the Digital Curation Centre seek to develop examples of Data sharing agreements and templates, in addition to data management plans and templates, as a means of developing an understanding of digital curation regimes sensitive to information rights management at point of use. That any exemplars of automated methods used to support data sharing agreements, resulting from projects such as the Consequence project, are included in the curation advocacy work with the aim of supporting requirements for trusted digital environments.

6.8 Architectural project digital records; curation at project phases

Peycere (2009)[125] describes two types of architectural project digital records and formats:

- Source, native or exchange files (for exchange within the project or with project partners)
- Output, distribution, print or archiving files

At the end of project phases a selection of the source or native files that were used for production of drawings in that project phase may be saved as output or archiving files. These output or archiving files act as an official record of the project. They may also act as evidence of which drawings, specifications, instructions, requests for information, agreements for variation and authorisations were issued between project parties and partners. AutoCAD files may be saved as DWF format, Photoshop files save as PDF etc.

The output files are intended to support printing and viewing of an authentic version of the document used in project and to provide confidence that the integrity of information has not been compromised by subsequent editing.

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[124] A collaborative research project partly funded by the European Commission for details see http://www.consequence-project.eu/index.html

[125] Peycere, D. (2009) The Architectural Practices as first curators of their Archives. Hybrid Architectural Archives: Creating, Managing and Using Digital Archives. Conference 10 - 12 June 2009. Netherlands Architecture Institute, Rotterdam http://conference.nai.nl/mmbase/attachments/525844/1.1_David_Peycer%C3%A9.pdf

In terms of Publication/Public domain it is the output files that will form the basis of sharing project and design information. The aim is to ensure that authorised official records are used in order to manage the reputation of the firm and the partners involved in the project and also representing the resulting construction without given rise to liability for the practice or the client.

Within a collaboration or shared research / design domain the output file format and printed drawings may form the basis on which instructions are conveyed to partners. Sub-contractors may produce hard copy drawing and specification or output file format digital documents for approval. These fixed forms may be deemed deliverables under contract.

The source or native files may be made available to partners as a source which can used to produce further plans (e.g. an electrical services layer to be added in to an existing architectural CAD drawing) but the fixed form (printed drawing or output file) may be regarded as the official source (with any accompany specification documents) to be used in case of disputed interpretation.

In the case of vector type drawing files as source files, using a package like AutoCAD, a cad file does not stand alone but requires a supporting description of the layers used in the cad file, the external (xref) drawing files used and the Pen settings to be used in generating a particular drawing. These may be captured by a statement of the conventions or standards used at the project or firm level. In order to provide for sharing within a project, or with partners, agreement is needed on the conventions and coding used. The project may have a specific role allocated to policing the requirements for common working as part of project management.

Drawing files may be used to produce the plan or drawing for a piece of work in a given phase of the project and while in production the source file or native file formats are required allowing editing and amendment. On completion and at some subsequent phase the drawing file will no longer be required as a source file. A selection of drawing files for the completed phases require to be saved as output or archiving files allowing viewing and printing of drawings but not editing. These output or archiving files stand in the practice or project as the official record. In some firm the printed version may regarded as the master version and signed by the Architect/Designer for the project and company archive.

The approach is to concentrate curation effort at the boundaries of domains and project phases. There may be an emphasis on selecting which files to keep, eliminating duplication and previous or intermediate version of now completed digital assets so that what is kept is the final accepted authorised version. The amount of storage space being used may be a concern. For key documents and drawing hard copies may be generated stored in the project and/or firms archive.

6.9 Curating the boundaries approach

From a practical digital curation perspective, tools like the DCC Curation Lifecycle model[126] should be applied at the boundary of domains or project phases so that considerations like appraisal and selection, ingest, preservation action, storage, access and reuse, and disposal are considered iteratively at the key stages throughout the project. The burden and effort of curation needs to fit with the pace of project activity and be seen to produce tangible benefits during the project as each stage comes to fruition.

In using developed digital environments, repositories services could be expected to support a higher degree of automation of curation services (for instance in the case interoperability supported through Building Information Model servers). Processes such as metadata enhancement could be expected to have automation support so that for example when a digital asset moves across the boundary from a shared to a public domain, some metadata additions are made automatically.

6.10 Obtaining value from Digital Assets

In providing for the care of digital objects in architecture one of the purposes of digital curation is to obtain and add value to the current or future use of the digital objects. For instance what can be done, through curation, to help provide for appropriate reuse or sharing of knowledge, information or data.

Much of the ethnographic evidence of information seeking in architecture and engineering practices shows that practitioners prefer to consult and ask colleagues as “experts” in seeking help with an issue or problem. This implies that knowledge of who worked on a particular project and descriptions of the expertise acquired needs to be curated as part of record of a project.

Demain, P. And Fruchter, R (2009)[127] clarify that in making use of knowledge from previous completed design projects in a current project (design knowledge reuse) that both the previously designed artefacts (product) and the process of how products were designed is what is shared or reused. This can be thought of in terms of

- Information about the product or artefact being designed (or previously designed artefacts, or previous projects)
- The process of design, the knowledge and experience gained in design work and deployed to support the development of a design project.

[126] http://www.dcc.ac.uk/docs/publications/DCCLifecycle.pdf

[127] Demian, P., Fruchter, R. (2009) Effective visualisation of design versions: visual storytelling for design reuse. Research in Engineering Design. Volume 19, Number 4 / January. pp. 193-204. http://dx.doi.org/10.1007/s00163-008-0051-4

Curation to support human designers

If we wish to use curation to support human designers, say by aiming to provide increased potential for design knowledge reuse, this requires an understanding of 1) the design project context and 2) the evolution history, the evolution of the item (product, component or detail) in question (through stages from concept, representation, to detailed realisation; with the alternatives considered and selected for development at each stage) and the rationale driving this design evolution.

In a learning context, programmes such as "Building Stories[128]" (developed at the University of California) aim to capture what actually happened in a project, including the rationale, constraints and conditions that led to design decisions. The outcome is a narrative description of the project as a case study. This forms part of the architectural record and requires curation.

The curation approach for architectural projects may require that the digital assets be supplemented by records generated through knowledge management techniques in order to capture the context of the design process through which the digital assets were produced and selected as contributing to design products.

Conclusions:

Support for research and design practitioners through the development of adequate digital curation infrastructure needs to be appropriate to the level of the investment of resources and expertise employed by researchers and designers in making use of digital techniques and tools.

The aim is to realise the benefit from the work of researchers and designers in producing digital assets; to best exploit the assets for value and return in contemporary use while providing for future uses and record through a managed digital resource base.

In the medium and longer term there is a need for automation of digital curation processes as part of the workflow in a digital environment to ensure the researcher or designer is best able to focus on the activity of research or design.

[128] For an introduction to the Building Stories approach see Heylighen, A. Martin, W. M., Cavallin, H. (2007). Building stories revisited: unlocking the knowledge capital of architectural practice. Architectural Engineering and Design Management. Vol. 3, pp 65-74. http://www.asro.kuleuven.ac.be/CAADPUBS/files/473.pdf

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