Knowledge Re-Use As Engineering Re-Use: Extracting Values From Knowledge Management

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Abstract

This paper presents a knowledge-sharing framework for achieving effective knowledge re-use within industrial organisations. This knowledge re-use paradigm goes beyond traditional engineering re-use which focuses solely on re-applying tangible resources such as hardware components, software objects or information repositories in new situations. The Knowledge-Sharing Management (KSM) framework describes how managers can align knowledge management strategy with corporate core competence strategy by articulating the values and risks of knowledge re-use. A general knowledge-sharing process is abstracted into a five-stage process model (adoption, adaptation, absorption, integration, dissemination), supported by four pillar components (organisational infrastructure, actor, technological enabler, sharing channel), which together guide the design of the work environment and processes by integrating the concept of effective knowledge re-use.

1 Introduction

Engineering re-use is the business strategy of using the firm's existing assets in new applications to create new assets. An asset can be a tangible or intangible resource, possessed or otherwise controlled by the company used in achieving corporate goals. In other words, re-use in general aims to exploit the value of economy of scale of assets by leveraging resources spent in one application in multiple other situations to reduce time to market, development resources, costs and risks.

Given that the value of knowledge now embodied in products, services and business processes attribute an increasingly larger portion of total costs, effective sharing of knowledge can give significant economic and lead-time advantages that potentially provide the key differentiating factor in any engineering re-use initiative. From a practical KM perspective, reusable assets can be knowledge of the know-how, know-why and know-what [Bla95] that constitutes an organisational memory [Wal91] "in the business about customers, products, processes and competitors" [KPM98]. In this aspect, knowledge is as much about whom you know as it is about what you know [Bad1991; Lot1998].

However, firms have hitherto often not considered the re-use of knowledge as part of the overall re-use strategy. The knowledge factor was either ignored as it would somehow be 'picked-up' by the person who attempted to re-use a component, or because knowledge could only be re-used unconsciously through some hidden cognitive processes and ad-hoc organisational routines that defy management. This study, conducted within a broader framework of engineering re-use project involving Cambridge University Engineering Department and 8 U.K. companies in the manufacturing engineering, chemical, aerospace, automobile and defence industries, is the initial work in developing the Knowledge-Sharing Management (KSM) framework to articulate the salient enablers and barriers to knowledge transfer. This initial work leads to an engineering re-use approach which considers the presently missing factor of tacit knowledge.

1.1 Beyond Re-Using Tangible Outputs

Traditionally, assets can be re-used in one of two ways, either through the re-use of hardware, such as physical parts or components, or through the re-use of software, such as libraries of functions or objects [Mol99; Rei97; Sut00]. Such a re-use paradigm is invariably based on the logic that development efforts can be minimised by re-using the *tangible outputs* produced from previous undertakings. *Tangible outputs* are often those where the knowledge of technology, design, experience of use and lessons learnt are embedded. This 'black-box' concept does not necessarily require thorough understanding of the detail of designs, implementation or the inner workings of the re-used object. One only needs to understand its external interface as an individual component in order to re-use it. This typically allows one to build upon others' *tangible outputs*.

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Recent attempts [Gru95; Pir95; Svi96] in the field of re-use include 'knowledge re-use' from a knowledge engineering approach. In this approach, it is the (formal) representations of knowledge that are really get re-used. Such imperative symbolic or connectionist representations of knowledge are in fact static snapshots of elicited domain knowledge extracted from subject experts. Another approach to 'knowledge re-use' are the attempts to re-interpret codified knowledge by data-mining repositories of information, searching attributes of scenarios to identify correlations of cases and repetitive patterns [Bor97; Bru99; Kuh97; Lin99]. Knowledge has to be codified with the use of a priori structured articulation processes. In other words, merely the *tangible outputs* are still being re-used.

On the other hand, knowledge held by people is dynamic and context dependent. Human cognition, subject to its limited processing capability, is able to adapt the conceptual model of knowledge to situate the application context [Men98a]. The adaptation is often aided by tacit knowledge developed through experience of use, professional praxis, and repetitive practice. The above 'black-box' approach to re-use is thus insufficient in allowing the knowledge user to understand and discern contexts of application. Accustomed to a 'black-box' approach, practitioners are often unaware of the part tacit knowledge is playing in re-use. They either ignore it or re-use it sub-consciously, preferring instead to grapple with tangibles. However, as knowledge increasingly commands a larger portion of the total cost and value of the whole product package, it is important to go beyond merely re-using the *tangible outputs*. To do so, knowledge re-use requires situated understanding and interpretation of the lessons learnt, organisational best practices and capabilities. It involves mobilising knowledge embedded in decision-making processes and organisational routines [Leo98; Nel82]. This implies re-using networks of interlinking knowledge as a whole rather than individual modules of knowledge. Effective re-use thus needs to encompass a holistic KS methodology as an integral part of the overall engineering re-use strategy. The following table summarises the different re-use approaches from a knowledge perspective:

Table 1: Different Re-use Approaches From A Knowledge Perspective

	Re-use Codified Knowledge In Tangible Outputs		**Uncodified Knowledge**
	Hardware	**Software**	**Intangible / Process**
Reusable Assets	Physical parts, modules, sub-systems, or facilities.	Database, information repository, component design, or software object.	Individual, group, organisational, and inter-organisational knowledge of regulatory, functional, positional and cultural assets.
Asset Characteristics	'Black-box' approach to re-use – definition of external interface determines reusability, design rationales are abstracted and information about implementation details are hidden inside the 'black-box'.		Lessons learnt, experience, skills, best practices and capabilities are re-used with historical, rational context specific details.
Knowledge Embodiment	Knowledge embedded in re-usable components as objects.	Knowledge encapsulated in objects, frames or codified in repositories.	Knowledge interwoven with decision-making process or organisational routines.
Unit Of Knowledge Re-Used	Individual component level.	Symbolic representations such as domain rules, models, frames or past cases.	Network of interlinking knowledge.
Knowledge Re-Used	Explicit and codified knowledge of know-how.	Elicited knowledge codified into symbolic representations.	Explicit as well as tacit knowledge, can be either codified or uncodified knowledge of know-how, know-why and know-what. Meta-cognitive knowledge [Kha98] with ability to familiarise new contexts, perspectives and roles in problem solving, learning and discovery.

	Re-use Codified Knowledge In Tangible Outputs		Uncodified Knowledge
	Hardware	**Software**	**Intangible / Process**
Solution Focus	Technology oriented solution, with IT as the centrepiece. Employ techniques of pattern matching, data mining or case-based reasoning to identify re-usable assets. Employ techniques of artificial intelligence and knowledge engineering to elicit and represent knowledge.		Human oriented solution, involving soft factors to facilitate resolution of organisational and cognitive issues. IT as a technological enabler to support the knowledge re-use process.
Critical Success Factors	Accuracy and speed of identifying relating reusable objects. Dimensions of success factors: traceability, storage, retrieval, and versioning.		Re-use strategy aligns with business strategy. Situated re-use approach fits with context of organisational culture and tasks. Re-use method not exceeding the cognitive capabilities of the work force.

The business implications from the above discussions are that organisations need to adopt two different strategies for re-use, with one based on the codification of explicit knowledge embedded in tangible objects, and the other on personalised sharing of tacit knowledge [Han99]:

Table 2: Knowledge Re-use Strategies

	Codification Strategy	**Personalisation Strategy**
Business Model	Standardised products.	Customised products.
Market Positioning	Mature products, well-understood tasks.	Product innovation.
Re-usable Knowledge	Knowledge embedded in *tangible objects* of hardware or software.	Knowledge interwoven with decision-making processes or organisational routines.
Knowledge Re-Use Strategy	Articulation relies on explicit codified knowledge, people-to-document approach.	Tacit knowledge shared only through person-to-person mentor.

2 Knowledge Re-Use Analysis

Current methods for knowledge re-use analysis can be viewed from three perspectives. Firstly, units of knowledge re-used from a stakeholder perspective along the supply chain [Por85], which may involve transferring of individual, group and organisational knowledge internal to the firm [Edv98; Nah98; Bak94] or appropriation of external knowledge across firm boundaries [Bad91]. Knowledge stakeholder perspective can be used to map potential sources of knowledge and where are the recipients [Hol98] of identified knowledge transfers. Secondly, knowledge development lifecycle [Sie99] is a useful guide to visualise the dynamic development of knowledge over time [Non95; Rei96]. The knowledge lifecycle captures the temporal dimension of dynamic knowledge development within the organisation. Knowledge demand and knowledge supply analysis can supplement to ensure availability of required knowledge to the recipient at any particular point in the knowledge lifecycle, serving as a guide for setting KS targets and assessing results of knowledge development over time. Thirdly is the dimension of re-usable knowledge content from a typological perspective [Pol66; Non91; Jen95; Bla95; Tee98a]. The knowledge typology categorises the characteristics of knowledge content to be shared, which, having considered the constraints of the characteristics, provides the basis for specifying appropriate technological tools and organisational environment to support the sharing activities.

Ruggles [Rug97] points out that information and communication technology tools are useful in augmenting KS activities by reducing the temporal, organisational, spatial and social distances. But their limitations, that tools themselves do not encourage or otherwise discourage KS [Rug97; Fra98], need to be recognised. On the impacts of organisational environment, Sanchez & Heene [San97b], Senge et al. [Sen94] and many researchers [Gal94; Non94; Bah92; Dav98a; Che96; Chi96; Mag98; Mal98; Man97; Mat96] have agreed on the importance of organisational forms on facilitating or otherwise hindering the flow of knowledge from the knowledge carrier to the knowledge recipient. Jensen & Meckling [Jen95] in particular proposes the use of agency and knowledge transfer costs to analyse the cost effectiveness of knowledge flow in terms of co-location of decision rights and possessed knowledge – that is, the role and responsibility structure delegating the decision-

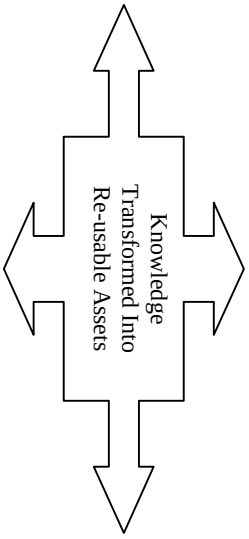
making authorities to the knowledge carriers. The design of organisational form should then take into consideration the sum of agency cost and knowledge transfer cost in supporting KS.

Dynamic Knowledge Development Lifecycle
Knowledge creation[1], growth, re-use, decay and attrition[2] over time.

[1]: [Non95]; [2]: [Rei96]

Unit Of Knowledge
Individual: Human capital[1] of creativity, skills, cognitive ability to learn, absorb and assimilate knowledge.
Group: Communities of practices.
Organisational: Social capital[2,3] of culture. Structural capital[1] of organisational form and infrastructure. Organisational capital[1] of business process and innovation.
Inter-organisational interface: Relationship capital[1,3] of customer-supplier network. Partnership / alliance network of knowledge links[4].

[1]: [Edv98]; [2]: [Nah98]; [3]: [Bak94]; [4]: [Bad91]



Knowledge Asset [Hal97]
Regulatory assets: Intellectual property, patent, trademark, copyright, licence, registered proprietary designs.
Functional assets: Employee, distributor, supplier know-how, know-why, know-what. Innovation capability.
Positional assets: Reputation of company, product brands, distribution network, established market entry barrier, customer base, unique access to suppliers and partnership networks.
Cultural assets: Not-invented here culture of re-use versus originality, openness to share re-usable assets.

Knowledge Typology
Tacit / Explicit [Pol66; Non91], General / Specific, [Jen95] Know-How / Know-Why / Know-What [Bla95], Positive / Negative [Tee98a], Autonomous / Systematic [Tee98a].

Figure 1: Transformation Of Knowledge Into Organisational Assets

It is the intention of organisations to transform knowledge into assets, which can be owned and possessed by firms having longer lasting values. Hall [Hal97] gives a clear categorisation of knowledge assets in terms of regulatory asset, functional asset, positional asset and cultural asset. However, though there are many existing theories on exploiting inter- and intra-firm knowledge [Bad91; Fra94; Mow96; Non94; Non95; Szu96; Tee98a], the linkage between knowledge as a resource and knowledge as an asset is under-developed. What is not clear is how the transformation takes place, how knowledge content can become re-usable assets and how to design the environment to facilitates KS activities so that knowledge can be transformed into assets and knowledge re-use can effectively take place. This is the gap which the KSM framework intends to fill. Figure 1 captures the relationship between the three knowledge re-use perspectives and the transformation of knowledge into knowledge assets.

3 Knowledge-Sharing Management Framework

Following on from the above knowledge re-use analysis, we have developed a holistic KSM framework focusing on the re-use and sharing of knowledge. This new framework is illustrated below.

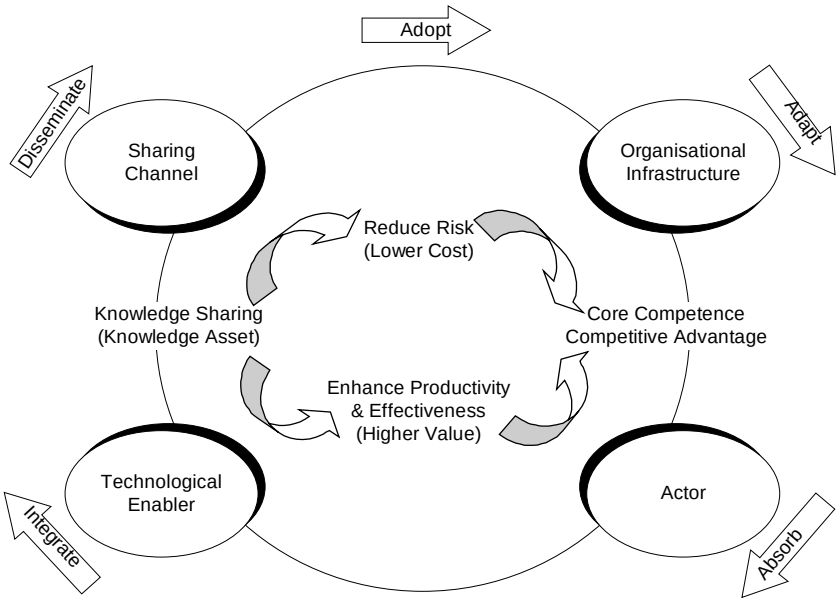


Figure 2: Knowledge-Sharing Management (KSM) Framework

3.1 Business Context

The business context is provided by the competitive advantages achieved through reduction of business risks (costs) and enhancement of productivity and effectiveness (values). A mapping of knowledge resources to targeted re-usable knowledge assets can be used to support the development of knowledge-based core competencies of the firm. The mapping identifies required knowledge resources to be mobilised to attain core competence development objectives. The targeted core competencies can provide the business rationales for KS initiatives in terms of values of enhanced productivity and mitigated risks. The risks mitigated can be upside risk of loss of business opportunities and core competence as well as downside risk of knowledge attrition. Gaps identified between the knowledge resource-knowledge asset-core competences mapping and the corporate strategic targets can be used to align the KS strategy with the business strategy of the firm. Development of the KS strategy can then be guided with the use of the above KS process model and the four pillars, which are also part of the new approach, and are described in the next two sections.

3.2 Knowledge Sharing Process Model

To achieve re-use, knowledge needs to be effectively shared between the knowledge carrier and the recipient. An exposition of an abstracted knowledge-sharing process is therefore useful. Previous attempts to describe the process include Nonaka [Non91], Boisot et al. [Boi97], Senge et al. [Sen94] and Rayport and Sviokla [Ray95]. By extending Lang's [Lan97] work, we have devised the following five-stage KS process model:

- *Adoption:* The recipient scans the environment, either through informal socialisation or systematic search, to identify threats and opportunities in abstracted knowledge, tacit or explicit, relevant to the tasks at hand. Background knowledge of the recipient is helpful in the identification process (to be aware what, where and who to look for). The knowledge identified could be fuzzy and not situated in the current context. The recipient also may not have the level of understanding in interpreting or applying the knowledge adopted.
- *Adaptation:* The logical cognitive processes of the recipient, subject to a limited processing capability, forces the adaptation of internalised conceptual models of previously adopted knowledge to the current task specific context. Domains of adopted knowledge are analysed, either consciously or unconsciously, to eliminate uncertainty, fuzziness and internal contradictions, resulting in 'implicit conceptual' or 'explicit interpretative' changes [Men98a].
- *Absorption:* The recipient can start gaining experience and competence in the use of the knowledge adapted as it is situated to the environment and task. An internalisation process starts to broaden the recipient's tacit knowledge base as causality of effects and consequences are learned through applying the knowledge. The recipient's perceptions of the world are framed by consultation with the adapted knowledge and interactions with its context. To have an effective internalisation process, the recipient must believe that the adapted knowledge is complementary to helping achieve his personal goal, and within the bounds of the organisational, social and professional norms he is operating in.

- *Integration:* Discrete pieces of contextualised knowledge are combined into a new whole, giving structures and coherence to shape the integration while reconciling inconsistency due to imperfect information from multiple sources of knowledge. Individuals with integrated knowledge either possess the skill of systematic problem solving with the ability to articulate the reasoning model and scientific theories behind, or already master the 'art' [Zub88] of the 'craft' [Non91] capable of applying knowledge in aggregates even in novel circumstances.
- *Dissemination:* Knowledge can be disseminated to other members of the organisation through personalised transfer (tacit-to-tacit) or multidirectional diffusion (tacit-to-explicit, or explicit-to-explicit). The scale of knowledge re-use then depends on the dissemination mechanisms employed, which are supported by the four pillars of KS described below.

3.3 Four Pillars

The barriers to KS implementation with respect to knowledge re-use and sharing can be categorised into four key areas. The four pillars of this framework are designed to help managers identify what focal areas need to be addressed in order to support the knowledge sharing process as exemplified in our model.

The *sharing channel* refers to the media selected and the modes of communication used to share knowledge. The sharing mode can be either 'unilateral co-operative' [Que97] – knowledge transfer is unidirectional when knowledge resides in one party but not in the other – or 'bilateral co-specialised' [Que97; Lan97] – when all parties involved do not possess the complete knowledge required, but each shares their individual separate pieces of knowledge to form a synergistic new whole. Unilateral sharing of explicit knowledge can employ synchronous or asynchronous communications, either geographically co-located or dispersed. Sharing of tacit knowledge, whether unilateral or bilateral, needs to employ personalised face-to-face interactions, socialisation and learning-by-doing as in mentoring apprentices.

Organisational infrastructure refers to the organisational form and how the designed form fits with facilitating the flow of knowledge from the carrier to the recipient. The design of organisational forms for KS, rather than basing on traditional segregations according to product, geographic, or functional boundaries, one must consider the co-location of decision rights and possessed knowledge to balance the trade-off between sub-optimal decisions and resources required for knowledge transfer. The design of the role and responsibility structure delegating the decision-making authorities to the knowledge carriers must fit with the cost-optimal point at the minimum of the agency and transfer cost curves.

Actor refers to those human issues that bring about the 'deep convictions' and 'changes in attitudes and beliefs' [Sen94]. Without such changes, sharing and learning cannot take place. Employees need to be convinced that any KS initiative is essential and beneficial to achieving their personal goals yet without diminishing their political power within the professional and social communities they operate in. The barriers of divisiveness and self-ownership must be demolished to nurture a KS accepting culture where people are capable of absorbing knowledge received, through the fact they are motivated, committed and willing to share knowledge. The following table summarises three focal areas to achieving this.

Table 3: Soft Issues Relating To Actor

Area Of Focus	Compensation And Rewards	Culture	Training & Cognitive Evaluation
Soft Issues	Motivation [5,6,7,8,9,10], Commitment [5,6,8,10,11,12,13,14], Loyalty [2,8,14,15,16], Value system and incentives [6,10,11,14,17,18,27].	Hiring policy [10,14,19,27], Mindset [5,25,26], Willingness [6,10,11,23,27], Professional/community norms [19,20,21], Management attitude and leadership [5,6,10,19,25,28,29], Originality versus not-invented-here culture [19,20].	Absorptive capability [1,2,3,4], Integrative capability [2], Marginal utility [4,22,24] of knowledge re-use and sharing, Divisiveness of knowledge [6,14,23].

[1]: [Kla97]; [2]: [Que97]; [3]: [San97a]; [4]: [Tee98a]; [5]: [Arg91]; [6]: [Van98]; [7]: [Mye96]; [8]: [Tam93]; [9]: [Dav98a]; [10]: [Mar96]; [11]: [KPM98]; [12]: [Non91]; [13]: [Non98]; [14]: [Dav96]; [15]: [Rei96]; [16]: [Pru97]; [17]: [Rug98]; [18]: [Dow98]; [19]: [Han99]; [20]: [Dav98b]; [21]: [Hal97]; [22]: [Tee98a]; [23]: [Pra90]; [24]: [Mil98]; [25]: [Ear99]; [26]: [Bei99]; [27]: [Sta89]; [28]: [Sen94]; [29]: [Edv97];

Technological enabler is the employment of information and communication technologies to augment KS activities. Technology tools must have the support of the other three pillars and the following characteristics, in addition to the general performance criteria of accuracy, relevancy, speed and reliability:

- *Discovery:* Re-usable knowledge must be accessible to systematic search to retrieve relevant bodies of

knowledge by matching seekers' requests with the best sources of knowledge.

- *Filtering:* Explicit knowledge retrieved from repositories must be filtered to extract pieces of knowledge that situates in the current context to avoid overloading the seeker's cognitive processing capability. Hypertext annotations to attach knowledge with compound objects of relating knowledge or versioning to capture historical background are example devices to convey the context.
- *Storage:* Explicit knowledge captured must be represented by an efficient codification scheme, thereby forming an organisational memory generating longer last value to the organisation. The attrition of knowledge can be reduced when knowledge is externalised and made available to others when needed.
- *Collaboration:* Tools can intermediate to broker knowledge seekers with carriers by bringing the two together in knowledge activities by reducing the temporal, organisational, social and spatial distances in collaboration.
- *Organisational Scale:* KS tools can provide consistent integrated architecture of structures and representations enabling uniform access to standardised knowledge repositories. Knowledge and its *outputs* can be leveraged throughout the organisation to benefit from economy of scale of re-use through mass distribution.

4 How Knowledge Re-Use Adds Value

The re-use of knowledge beyond tangible outputs has implications for businesses in three ways. Firstly, any knowledge re-use strategy must recognise the limitation of mass volume transfer of tacit knowledge. As tacit knowledge underpins the understanding, evaluation and application of all knowledge, it is the key component in any knowledge re-use process. But since tacit knowledge is more difficult than tangible assets to imitate and replicate, its marginal cost of re-use can be difficult to justify. Such difficulty limits the values of economy of scale achieved from the mass volume re-use of tacit knowledge. This issue should then draw management attention to geographic and decision authority co-locations. In practical terms, the former is the organisational hierarchy designed to align the roles and responsibilities of knowledge carriers with decision makers and implementers. The latter are the organisational infrastructures designed to bring together knowledge carriers and recipients.

Secondly, the implication of the context dependent nature of knowledge is that it is futile to decontextualise knowledge. In such a case, knowledge will become information, and a knowledge carrier will lose the ability to discern whether knowledge possessed is relevant to the tasks at hand. The situated cognition argument concerning re-use is, if knowledge is context dependent, and context is ever changing in a constant state of flux in the real-world, then re-use is logically impossible, since there is no one model of knowledge known that can fit in all situations. As Menzies [Men98b] eloquently pointed out, any knowledge engineering approach excluding the modelling of the environment within which a knowledge base must operate will fail. The piece that solves the puzzle is the tacit knowledge embedded in the KS process. Tacit knowledge provides the clue allowing individuals to adapt the conceptual model in their minds and also clarifies the contextual correlations between the original and the current situation. The search for re-usable knowledge must therefore be found within the KS process model described in (2.2). To elaborate, values attributed to re-usable knowledge depends on the context as well as the internalisation of the context imposed by the knowledge 're-user'. It is in this sense difficult to attribute quantitative consensual values directly to re-usable knowledge. Any risks and rewards analysis of knowledge re-use should thus base on indictors that measures the effect of knowledge re-used to the specific tasks at hand, that is, an indirect measurement approach with its valuation subject to fluctuations with changing application contexts and to how well the knowledge is internalised.

Thirdly, IT delivers its values by efficiently packaging knowledge into objects, making distributions for re-use in scale possible with explicit knowledge. IT enhances the productivity of knowledge 're-user' through the five key roles of discovery, filtering, storage, collaboration and organisational scale. However strong is IT's ability to raise the process speed and level of standardisation, IT needs to be able to support the other three pillars to realise the full benefits of the richness and dynamism of KS activities.

5 Future Work

Faced with intense competitive pressure from globalisation and shortened product development lifecycle, companies need methods to exploit maximum values from their existing knowledge assets to provide the edge in competition. This paper describes our work to date in extending the established idea of engineering re-use to include the more intangible concepts of knowledge re-use. It describes a generic Knowledge-Sharing Management framework demonstrating how knowledge management can realise practical business benefits in the area of knowledge re-use. Our next step is to apply and further develop this framework by operationalising it with our industrial partners in the financial and manufacturing sectors, refining the framework based on the feedbacks and empirical data gathered in the process. Our final aim is to provide a knowledge sharing management methodology that provides practical guidance on the design of organisational environments that facilitates the implementation of knowledge sharing and re-use programs.

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