Chapter 3: Literature Review:

Conceptual Framework

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This Chapter portrays the findings from previous researches and explains the fundamental knowledge including the developed conceptual frames on which this research is based upon. This chapter also entails the gaps in the previous researches, the research problem, the research questions and the research objectives.

3.1 Review of Existing Literature

The researcher's extensive literature review covered over three hundred published literatures (referenced in Bibliography section) relevant on the subject. Based on the need for the research discussed earlier, the review of the existing literatures have been under **two main themes –**

I) Existing Researches/Models/Practices in multidisciplinary Engineering Design Management that cover management of different engineering designs including mechanical/piping designs, &

II) Existing Researches/Models/Practices in Piping Engineering Design Management that cover specific management of piping engineering designs only.

The theme-wise reviews of the subject existing literatures are discussed in the following paragraphs.

I. Existing Researches/Models/Practices in Multidisciplinary Engineering Design Management:

Research in discipline independent or multidisciplinary engineering design management reveals that Design Engineers suffer from *decision dilemmas* leading to degradation of product quality (Turner, 1985; Owen, 2006) and limiting design management excellence which in turn lowers competitive advantage and this calls for an effectively efficient design management model (Ughanwa, 1988; Mozota & Kim, 2009).

Engineering Design has so far been managed by various designers in several differing methods & ways *devoid of any formal management model guiding the processes* (Zanella & Gubian, 1996). Some researchers have identified this gap, researched & built some management models that are discussed in the following paragraphs.

The development of the first formal design management model can be traced back to the Waterfall Model (Royce, 1970) wherein sequential management of seven engineering steps are considered in a top-down approach. This model has been based on an assumption that all activities of a particular step would get completed before moving on to the next step & that there has been no provision of two-way interaction between the steps, and hence, this model suffered widespread criticism from its researcher himself & others (Royce, 1970; Parnas, 1986; McConnell, 2004).

Some researchers identified the problem of managing engineering design data that is a part of the design process and built an engineering data management system for Computer Aided Design or CAD (Heerema & Hedel, 1983; Miles, Gray, Carnduff, Santoyridis, & Faulconbridge, 2000). This system is not for managing the entire design process but only one part of it. A *real management* *system for managing all the processes of engineering design* has been felt though subsequent research studies (Turner, 1985). Research in the management of CAD processes in ship-building also highlighted similar problems (Beames, 1987). Research in search for design management excellence unearthed the weaknesses existing in design management practices leading to gradual erosion of competitive edge and highlighted the need for integrating the design management functions (Ughanwa, 1988). Design data handling & interactions with the other processes of construction have also been researched & modeled but the integrated model does cater to the management of the internal design processes (Brown, et al., 1995). The need to provide support decisions throughout the design process is a worldwide acclaimed fact requiring the systematic integration of CAD tools into the design management process (Sharpe, 1995; Twigg, 1995). Konemann (2011) stressed the need to integrate design decision support systems into the processes of software engineering design management (Konemann, 2011). The integration of early & late process design stages have been researched upon purely from an engineering point of view and a framework has been developed (Karcanias, 1995). Karcanias' (1995) research however does not touch upon the design decision-making problems inherent in the design processes, from a management side as have been highlighted by others.

NASA (National Aeronautics and Space Administration, USA) follows an eight step design process that is custom build for only the aeronautical & space industry– Identify the Problem, Identify Criteria & Constraints, Brainstorm Possible Solutions, Generate Ideas, Explore Possibilities, Select an Approach, Build a Model or Prototype, and Refine the Design (NASA, 2012). Researchers at the University of Cambridge have identified four basic phases of the design process namely Clarification of the Task involving problem, criteria & constraints identification, Conceptual Design involving brainstorming possible solutions, generating ideas, exploring possibilities & selecting san approach, Embodiment Design involving building a model or prototype, and Detail Design involving refining the design (Wallace & Burgess, 1995). Other researches also recognized these four basic phases of the design cycle (Erden, 2004). The Cambridge researchers have also substantiated the business need for switching from the traditional design method of relying on the experience & insight of talented designers to a validated/verified design method/model that manages the design processes fully. CAD systems tend to focus on the design product from an engineering point of view only thus leaving the remaining design processes' decision dilemma with the design manager. To address this gap, these researchers have created an Integrated Design Framework which however, is limited by its applicability to the Aerospace, Transportation & Medical Equipment industries only (Wallace & Burgess, 1995). Some other researchers have identified "*six detailed phases of the design process namely:*

1. *Establishing a Need Phase* involving the idea, proposal, etc.,

2. *Analysis of Task Phase* involving investigation of the need, specification, task clarification, etc.,

3. *Conceptual Design Phase* involving possible concept synthesis, product principle, etc.,

4. *Embodiment Design Phase* involving basic product design, feasibility testing, etc.,

5. *Detailed Design Phase* involving feasible alternatives & detailed solutions, detailed design, detailed specifications, etc., &

6. *Implementation Phase* involving testing & refinement, commercialization, etc.," and, highlighted the links between engineering design process and creative process from a cognitive psychology approach that is all encompassive (Howard, Culley, & Dekoninck, 2008; Dutta, 2013a).

Some researchers have built a framework to support management decisions in the strategic design of the distribution system, applicable to the logistic system in the automotive sector (Manzini & Bindi, 2009).

Since the 1980s, CAD tools have been developed that simplify only some of the tasks of the design process (like product modeling & product analysis) whereas *integration with the other tasks is through ad hoc manual processes* (Zanella & Gubian, 1996). Moreover, the importance of *dynamic feedback* in knowledge management is well recognized (Dearnley & Smith, 1995). Catering to these needs, some scholars have proposed a conceptual design management model built by eliminating the *design manager's problems of incremental changes, dynamic checks & feedbacks, design project organization, control of CAD, design methodology, co-ordination of large sets of design data and maintenance of design rules & integrity* (Zanella & Gubian, 1996). However, this research has assumed the design manager as a syntactic controller in an intelligent CAD software and hence the research results cannot be flatly applied in solving the problems of a human design manager. Also this research is in the electronics design industry and the research model's applicability to other industries' design management has not been validated. However, the abstractions of the problems are applicable to present day multidisciplinary design management (Zanella & Gubian, 1996).

Some researchers have built a Neutral Object Data Model that classifies & codifies design information for structuring design data in a conceptual data model applicable only to the building construction / architectural industry (Kiwan & Munns, 1996). Some other researchers built a Database Infrastructure framework for design history information as an augmentation to the Standard for the Technical Exchange of Product Model Data or STEP in terms of supporting design process models (Shah, Jean, Urban, Bliznakov, & Rogers, 1996). Research has substantiated the *need for design process interdependency based conflict areas,* which has been catered to by the Discourse Model that treats assertions as facts & not as conflict (Case & Lu, 1996). This model manages the assertions of design engineers through a specified closely-coupled interaction module that explicitly detects conflicts, facilitates rationalization/negotiation through increased interaction and finally the opinioned solution subject to review & revisions. However, this research model is applicable specifically for the architectural industry (Case & Lu, 1996).

Visser (1996) has qualitatively researched into the functions of analogical reasoning in design problem solving (Visser, 1996). Visser used a cognitive-psychology approach in observational studies of professional designers & identified two types – a. *Action-Execution (AE) Analogies & b. Action-Management (AM) Analogies*, in which, AE types are the ones normally employed by designers in a specific design problem-solving whereas *AM types are the ones employed after the designer gets the solution for the AE types and these AM types are used for managing the specific design problem solution most-economically in the context of the global design problem, of which, the specific design problem is just a part* (Visser, 1996).These findings give an insightful direction in the development of systems for managing engineering design, an area of future research (Visser, 1996).

Design process involves a lot of interactions between the target design user & the design expert and hence is crucial to an efficient design management system. Research on this using semantic discourse analysis and rhetorical techniques undertaken by Parent (1997) identified a classification scheme in the form of a question-answering mechanism consisting of 5 main categories – Elaboration, Enablement, Validation-Current-Model, Validation-Future-Model and Clarification through different question types to facilitate communications between the end-user (client) & domain-expert (designer). Parent (1997) also validated this question answering mechanism & opened up the further research area for studying the design management dialogue process (Parent, 1997).

Design management in an integrated CAD environment has been studied from a data management approach & a research model has been built that connects the different design data applications which improve the design management process in the architectural industry (Kim, Liebich, & Maver, 1997). The importance of engineering design knowledge sharing as a part of the design management process has been recognized and an information system for improving the sharing has been built which however does not cater to the other processes of design management (Jokinen, 1997; Dong & Agogino, 1998; Herder & Weijnen, 1999).

Previous qualitative research work substantiates the *neglect & absence of systematic feedback to the engineering design management processes* leading to a design output that is much inferior to what could have been achieved through structured feedback management (Busby, 1998). Chen, Frame, & Maver's (1998) research shows us how the *human-level interactions among multidisciplinary design teams have been ignored & left to be managed by differing human opinions leading to designing bottlenecks* that can be removed through an efficient studio environment managing the human interactions within design teams in architectural industry (Chen, Frame, & Maver, 1998). As seen, there have been quite a number of researches & models on Design Management in the architectural/building/construction industry, all substantiating the *design manager's problems of multidisciplinary collaboration, non-value adding activities, reworks, data management & conflicts,* and proposing some improvements on the existing practices (Kiwan & Munns, 1996; Case & Lu, 1996; Kim, Liebich, & Maver, 1997; Chen, Frame, & Maver, 1998; Kalay, Khemlani, & Choi, 1998; Lee, Sause, & Hong, 1998; Chapman, 1998; Chua & Tyagi, 2001). It can also be seen that there have been considerable research in design data/archive management since that plays an important role in a design engineer's task of referencing (Heerema & Hedel, 1983; Brown, et al., 1995; Zanella & Gubian, 1996; Kiwan & Munns, 1996; Kim, Liebich, & Maver, 1997; Dowlatshahi & Nagaraj, 1998; Willaert, Graaf, & Minderhoud, 1998; Peng & Trappey, 1999; Miles, Gray, Carnduff, Santoyridis, & Faulconbridge, 2000;

Tiwana & Ramesh, 2001) (Concheri & Milanese, 2001; Wang, Shen, Xie, Neelamkavil, & Pardasani, 2002; Hicks, Culley, Allen, & Mullineux, 2002).

Research in collaborative engineering has highlighted that documentation of design decisions are typically made after the project ends which leads to unwanted leaving out of steps that are crucial to retrieve the design processes of that project later on & hence this calls for an indispensable need for *full documentation of the design decisions during the design product development itself* (Willaert, Graaf, & Minderhoud, 1998). The ever-increasing challenge of companies to remain competitive in today's extremely volatile market calls for *systematic innovation alongwith optimization of cost, quality & flexibility* (Willaert, Graaf, & Minderhoud, 1998; Walton, 2004; Stark, et al., 2010). "Despite the obvious importance of systems innovation to continued organisational existence, research suggests that *innovative efforts are ineffectively managed*, cumulating in over half failing to achieve their goals" (Dooley & Sullivan, 2003; Li, Li, Wang, & Liu, 2010; Xu, Houssin, Caillaud, & Gardoni, 2011; Dutta, A Theoretical Model of Innovation Integrated Engineering Design Management, 2013). *Lack of time, poor planning & management of engineering design have been found to be the main limiters to innovation, necessitating structured management techniques to integrate systematic innovation into the design management cycle* in order to sustain firm's competitive advantage (Salter & Gann, 2003). Xu et al. (2011) showed how design innovation can be integrated into knowledge management through 4 characteristics of *explicitness, novelty, importance & usability* with due regards to traceability & trustworthiness of knowledge for fostering continuous innovation (Xu, Houssin, Caillaud, & Gardoni, 2011). Artificial intelligence technology still lacks basic theory about human creative thinking and decision mechanism and so existing design software systems have creative limitations, and thus human-based creativity for product innovation appears to be the most pragmatic approach (Liu, Li, Pan, & Li, 2011).

More democracy in organizational structure leads to less blockages to innovation (Shoham, EranVigoda-Gadot, AyallaRuvio, & NitzaSchwabsky, 2012).

The ISO Standard STEP provides a technology to solve product data exchange problems but *does not support semantic communication between the design engineering processes* (Martino, Falcidieno, & Habinger, 1998). Poor management of engineering design in USA has created 10 major problems/concerns of the design management firms - *(1) making a profit, budget, (2) meeting schedules and deadlines; (3) change order and/or scope management; (4) internal communications; (5) quality control; (6) client communication; (7) lack of experienced engineers; (8) low fees/determining fees; (9) planning/scheduling and (10) time management* (Ogunlana, Lim, & Saeed, 1998). These problems have been shown to be depreciated by the use of an efficient design management model that has been built by the researchers with the aim of addressing these concerns but the research has been limited to civil engineering design only (Ogunlana, Lim, & Saeed, 1998).

A review of how information management is dealt with in today's design management departments shows that the existing practices are *mostly manual with some semi-automated processes (for example CAD outputs) devoid of any formal management model to facilitate seamless collaboration & concurrency control* in creative multidisciplinary engineering design (Jacobsen, Eastman, & Jeng, 1997). A review of engineering change management shows that *engineering change is predominantly seen as a problem rather than an opportunity to cause incremental product development* thus necessitating effective design management practices (Wright, 1997).

Lee, Sause, & Hong's (1998) research into Design Management highlights two concurrent models – a Product Model for managing the information created during the design process and a Process Model for managing the associated design activities. For an *improved understanding & implementation of design, indispensable is the need for a design management model that caters to the whole of the design process* (Lee, Sause, & Hong, 1998). Hence, Lee et al. build an entity based sequentially integrated model that uses product entities and process entities to represent design information and design activities, respectively. This model has been validated in building structural design only & has not been validated for other engineering design systems (Lee, Sause, & Hong, 1998).

Liu, Tang, & Frazer (2004) presented a software based design management framework using hierarchical multi-agent system architecture to systematically manage the design activities. This framework aids multidisciplinary collaboration but does not solve the design manager's other problems like non-value adding activities, reworks, data management & conflicts, dynamic checks & feedbacks & systematic innovation integration as have been highlighted by other researchers discussed earlier. Also this framework is an intermediate one requiring further research & development of the software in order to be able to cater to the full range of integrated design cycle activities (Liu, Tang, & Frazer, 2004). Komoto & Tomiyama (2012) developed a similar framework for mechatronics products (Komoto & Tomiyama, 2012).

The *requirement of collaborative design negotiation environment for conflict resolution* is a research proven fact (Case & Lu, 1996; Pena-Mora & Hussein, 1998; Wang, Shen, Xie, Neelamkavil, & Pardasani, 2002) that traditional meeting environment does not cater to owing to its inherent human constraints like poor communication in either quality, quantity or form (Pena-Mora & Hussein, 1998). Conflicts are barriers to design management excellence, conflicts originate in interfacing points and conflicts can be effectively handled by shared understanding through efficient design project management (Kleinsmann & Valkenburg, 2008). Design conflicts occur between designers of same discipline (Ouertani, 2008), between disciplines (Case & Lu, 1996) and between design teams & client (Wong, Lam, & Chan, 2009).

Engineering design has been traditionally & most-widely been managed in a top-down approach but recent trends suggest a movement towards a *flatter structure of design teams consisting of a balance between top-down & bottom-up management methods that enables more effective design management products* (Owens, 2000; Dias, Subrahmanian, & Monarch, 2003).

In any managerial task, if the difficulty level is high, *broad-scope information is required continuously to help the manager understand difficult tasks more clearly* (Choe, 1998). Under high task uncertainty as in the case of design engineering (Lee, Sause, & Hong, 1998), *aggregated and timely information through high user participation is positively related to high performance* (Choe, 1998). Currently, there is a *lack of holistic approach to the management of design* (Chapman, 1998). Besides poor design management, the problem of design project duration overrun has now been attributed to the *loss of key personnel (attrition) resulting in disruptive communications, reworks, excessive work pressure on existing employees and decreased morale* which need to be recognized & systematically taken care of by a proactive design management system (Chapman, 1998). Another major reason of design project overruns is *underestimation of the design effort* for which the existing methods like PERT/CPM (Program Evaluation & Review Technique/Critical Path Method) have been found to be ineffective (Bashir & Thomson, 1999) since they do not have feedback & iteration that is very common to design (Smith & Morrow, 1999) but methods using metrics to estimate design effort & time are found to be more suitable which however, is a subject of further research (Bashir & Thomson, 1999; Bashir & Thomson, 2001; Xijuan, Yinglin, & Shouwei, 2003).

In order to sustain the competitive advantage of the company effective design management is indispensable (Bruce, Cooper, & Vazquez, 1999; Chua & Tyagi, 2001; Heller, Jager, Schluter, Schneider, & Westfechtel, 2004; Andersen, Nycyk, Jolly, & Radcliffe, 2005; Owen, 2006; Mozota, 2006; Mozota & Kim, 2009; Mozota, 2010). Effective design management is also required to *prevent time loss* (e.g. reworks from a variety of causes, conflicts, etc.), *opportunity loss* (e.g. job dissatisfaction of employees leading to higher attrition, product quality lowering leading to lower customer satisfaction and loss of market to better competitors, etc.) and *revenue loss* (e.g. shrinking market share, the various effects of time & opportunity losses on the revenue, etc.). Effective design management is also required to *prevent time loss* (e.g. reworks from a variety of causes, conflicts, etc.), *opportunity loss* (e.g. job dissatisfaction of employees leading to higher attrition, product quality lowering leading to lower customer satisfaction and loss of market to better competitors, etc.) and *revenue loss* (e.g. shrinking market share, the various effects of time & opportunity losses on the revenue, etc.). For example, practical site requirements may vary in quite many aspects from the theoretical conditions considered in design and thus not communicating with end users can cause a lot of rework in the later urgent stages leading to time & manhour wastage; interdisciplnary conflicts, arising from interfacing disciplines not interacting with each other to understand other disciplines' specific requirements may have conflicts at later stages, again leading to time loss; haphazard management of design lowers cycle efficiency leading to excessive work pressure, decreased job satisfaction that causes higher attrition as well as loss of competitive edge which, in turn decreases the business opportunities for the company; all these issues plague the management of engineering design management cycle and reduce the company's revenue in the long run (Visser, 1996; Lee, Sause, & Hong, 1998; Kiwan & Munns, 1996; Case & Lu, 1996; Kim, Liebich, & Maver, 1997; Chen, Frame, & Maver, 1998; Kalay, Khemlani, & Choi, 1998; Lee, Sause, & Hong, 1998; Chapman, 1998; Chapman, 1998; Swink, 2000; Dutta, 2013a).

Research has proven that the companies who do not have effective engineering design management practices/models are much less successful in business than the ones having it (Bruce, Cooper, & Vazquez, 1999) as the absence of an effective design management model induces loss of competitive edge of the company in terms of time loss, opportunity loss & revenue loss (Turner, 1985; Ughanwa, 1988; Wallace & Burgess, 1995; Kiwan & Munns, 1996; Lee, Sause, & Hong, 1998; Chua & Tyagi, 2001; Owen, 2006; Mozota, 2006; Mozota & Kim, 2009; Sun, Williams, & Evans, 2011). Previous research has further proven that a model for integratively catering to all identified issues/challenges becomes innately effective in flourishing the competitive advantage of any company (Turner, 1985; Ughanwa, 1988; Wallace & Burgess, 1995; Kiwan & Munns, 1996; Bruce, Cooper, & Vazquez, 1999, Lee, Sause, & Hong, 1998; Chua & Tyagi, 2001; Owen, 2006; Mozota, 2006; Mozota & Kim, 2009; Sun, Williams, & Evans, 2011).

Research in large & medium sized mechanical engineering design firms shows lack of design management control and recognizes the *need for an efficient design management system that empowers designers to actively influence existing practices, involves them in consultations about the overall strategy and creates a sense of identity with the products they design* (Lauche, 2005).

Team decision making has been proven to be more effective by *increasing simultaneity of the product development processes* through concurrent engineering methods (Moffat, 1998; Roemer & Ahmadi, 2010) and this can be suitably managed through an efficient design management system (Willaert, Graaf, & Minderhoud, 1998). Previous research has also shown that the *design problem of making the best design decision is more for senior design engineers compared to the lesser experienced ones* since the senior engineers have a lot more design alternatives to choose from than their juniors (Atman, Chimka, Bursic, & Nachtmann, 1999). Also *losing these senior engineers due to any* *unanticipated event like employee dissatisfaction, low work morale, etc. proved to be very harmful to design project quality & completion schedule* (Chapman, 1998). Inspite of worldwide recognized engineering standards (for example ASME, BS, ISO, etc.) governing the design of products, a recent survey conducted by the UK Design Council concluded that an average product could be redesigned to reduce manufacturing costs by 24% and to improve market demand by 29% thereby challenging the existing products' designs and invariably opening the gates for *research on design management for better design products* (Hurst, 1999).

Crafts knowledge or practical manufacturing/production/construction knowledge has been seen to augment and sometimes modify the engineering design practices for the common goal of making a better designed product & hence the *integration of this two way feedback loop between the design department & the manufacturing/production/construction department in the design management process* has been considered to be of paramount importance (Yair, Tomes, & Press, 1999). Design management in small businesses have been studied in terms of sourcing the designer, briefing the designer & evaluation of design, and, the research proved that *the more effective the design management practices of a firm are, the more the firm is successful in business* (Bruce, Cooper, & Vazquez, 1999). Design involves a lot of interdisciplinary as well as intradisciplinary negotiations that are best managed through an ergonomic approach (Owens, 2000; Detienne, Martin, & Lavigne, 2005). Research has proved that ergonomic criteria is often neglected in design leading to product's quality of usability being compromised and this calls for *integration of the ergonomic criteria into the design management process* itself (Wulff, Westgaard, & Rasmussen, 1998; Karwowski, 2005).

It has been observed that engineering researchers have typically focused on formal structures involved in engineering design decisions (Pahl, Beitz, &

(Ed.) Wallace, 1996; Smith & Morrow, 1999), while management research has concentrated on the myriad organizational issues involved in product development (Brown & Eisenhardt, 1995; Smith & Morrow, 1999). Both research traditions have value to the engineering design management researcher. Some researches identify the common goal of Engineering Design & Management Research as building tested knowledge for use, and, portray *future management research as design science* in contrast to the present conception of management research as an explanatory science, where both academics could thrive and managers could have confidence (Tranfield, 2002). The growing invasion of nature by humans today necessitates an ecological engineering approach to serve as one of the bases of engineering management (Xu & Li, 2012).

A review of the different design management models like AIDA (Harary, Jessop, Stringer, & Luckman, 1965), Q-GERT (Taylor & Moore, 1980), DSM (Steward, 1981), Petri net (Bretschneider & Lagger, 1992), Parallel scheduling (AitSahlia, Johnson, & Will, 1995) & WTM (Smith & Eppinger, 1998) reveal that these models focus either on *development lead time or development cost or product specifications* i.e. these models focus only on one aspect of the design management process and on top of it, these models *lack practical applicabilities since these models have been developed from a purely academic context & not by people engaged in design engineering activities* (Smith & Morrow, 1999). Thus, Smith & Morrow's research reinstates Bruce et al.'s research highlighting need for practical crafts knowledge integrated design management model. Some other researchers have proposed a web based design management framework that reduces some of the design manager's problems of sequencing processes, monitoring flow, controlling flow & displaying results of a multidisciplinary design project at the macro level, but does not cater to the other design management problems (Rogers & Salas, 1999) like incremental changes, dynamic feedbacks, innovation integration, etc. already discussed.

Cho & Eppinger (2005) have built a process model that uses design structure matrix (DSM) representation to capture the information flows between tasks and a simulation-based analysis to account for many realistic aspects of design process behavior which are not possible in previous analytical models (Cho & Eppinger, 2005). This model although facilitates better design project planning & control, but suffers from inaccuracy since it assumes that *processing time of each task is independent of those of other tasks whereas in practice it is not*_and also, this model does not consider *bi-directional information exchange* that is very common in design practices (Cho & Eppinger, 2005). A design management model specifically applicable for remote & environmentally sensitive sites have been developed by researchers through two case studies catering to the construction sector (Kestle & London, Towards the Development of a Conceptual Design Management Model for Remote Sites, 2002; Kestle, Remote Site Design Management, 2009). Researchers Choo, Hammond, Tommelein, Austine, & Ballardd (2003) built a design management model applicable only for the detailed designing phase not the basic engineering or other phases of the design management cycle (Choo, Hammond, Tommelein, Austine, & Ballardd, 2003). *Designers lack knowledge of management concepts leads to ineffective management of engineering design by the design engineers and this necessitates an efficient model* of engineering design management (Mozota, The Four Powers of Design: A Value Model in Design, 2006). Mozota built a conceptual framework of design management based on four powers of design namely Design as Differentiator, Design as Integrator, Design as Transformer and Design as Good Business that reduces the designer's difficulty in implementing a value model in their everyday practice, but the framework, however, does not consider the relationships among the processes of product design cycle (Mozota, 2006). Some other researchers used an object oriented approach to build an integrated model of engineering design management named CoMoDe that may well form the basis for developing an integrated software model of design management (Gonnet, Henning, & Leone, 2007) but does not facilitate innovation integration or dynamic feedbacks that are indispensable to make design management proactively successful in today's competitive world as envisaged by other researches discussed earlier.

Some researchers presented a model for managing the design processes limited only to the conceptual or front-end design phase (Brunettia & Golob, 2000; Tzortzopoulos, Cooper, Chan, & Kagioglou, 2006). Some other researchers studied electronics engineering design teams to develop a human-centred soft system method based on ethnography to facilitate design team's performance but the research is also limited only to the early & conceptual design phases in electronics design projects (Jagodzinski, Reid, Culverhouse, Parsons, & Phillips, 2000). A study of aerospace design teams defines *engineering design as complex, elaborate socially-mediated activity much of which is tacit* and shows how *ethnographic approach is indispensable to study teamwork in design teams* (Baird, Moore, & Jagodzinski, 2000). Lloyd (2000) has also studied engineering design teams from an ethnographic approach involving mainly qualitative data and found that *storytelling as a common language in design teams* that facilitated better design (Lloyd, 2000). Research has proven that information strategies applied to the design process substantially improves project performance (Moreau & Back, 2000). Owens' (2000) research establishes the current trend towards *flatter & looser structures in design teams so that it empowers team members* to assert their own expertise when needed (Owens, 2000). Owens' research also shows that the *primary mechanism for decision making in design teams is through informal negotiations*. Research on role of engineering design in innovation has identified *that design acts as an agent of innovation and two ways are identified as innovation integrator & innovation broker,* whereas other ways of applying design activities to promote innovation require further research (Bertola & Teixeira, 2003).

A qualitative research on future design engineering competency requirements forecasts that although *technical competencies will remain equally important in the future, their relative importance will decline as a consequence of the emerging importance of non-technical competencies like design project management in order to cater to the increased business need for incremental innovation* (Robinson, Sparrow, Clegg, & Birdi, 2005). The design engineer's position in the product development process allows them to bridge the gap between market conceptualization and the realities of production and hence research shows that in addition to more rigorous technical skills to perform their engineering work, the design engineer's job has enlarged from technical specialist to participating member of a cross-functional team where *communication and cooperation* are key success factors (Hong, Vonderembse, Doll, & Nahm, 2005). A *good design leader must have open attitude, objectivity, block removing capacity, proactive appreciation for passion & creativity and an understanding nature* (Lee & Cassidy, 2007). Today's increasing need of flexibility calls for a management system that allows reformulations of project objectives along the way (Lenfle, 2008).

Another research reinstates previous research work that *systematic design management positively impacts internal internal quality outcomes such as scrap, rework, defects, performance, and external quality outcomes such as complaints, warranty, litigation, market share* (Ahire & Dreyfus, 2000). Swink's (2000) research also recognizes other researchers' views that an design integration is a co-ordination of product & process design activities performed in design teams & reinstates the *need for holistic design management integration together with innovation aided by top management* (Swink, 2000). Another research in electronics engineering design teams *reinstates the design management dilemmas of design co-ordination & team integration* highlighted by other researches discussed earlier & points towards the *need for a flexible & dynamic design* *management system* (Reid, Culverhouse, Jagodzinski, Parsons, & Burningham, 2000).

For large and complex design-processes traditional ad-hoc approaches to process design do not suffice (Moody, 2005; Aken, 2005). Prescriptive knowledge models' practice in process design is still too limited owing to the reasons that the potential of professional process design to produce effective and efficient design processes is still underestimated as well as the potential of prescriptive design knowledge to support that professional process design (Aken, 2005). Design effectiveness, in recent years, has become subjective instead of being objective, and this necessitates the need for automation in the design management in order to expand horizons (Woudhuysen, 2006).

Design is positioned at the point where art & science meet and so design focuses on possibilities & opportunities in an imaginative way (Rieple, 2004). Although there are lots of evidences that innovation induces economic success, senior managers tend to block innovation since innovation has uncertain predictability that may risk shareholders' returns from their investments (Rieple, 2004). Neufville (2004) shows that this uncertainty can be actively managed & exploited by a profound positive shift in our mindset & attitude towards *uncertainty meaning the entire distribution of possible outcomes* instead of just the general synonym for risk and, this shift is powerful enough to drive the greatest innovative opportunities (Neufville, 2004). On the flip side of uncertainty is imprecision that can also be managed through imprecise probabilities that reduce to precise probabilities when the available information is extensive (Aughenbaugh, 2006).

The *indispensable need for systematic management of engineering design* has time & again been proven by a number of researches in various engineering sectors as well (Royce, 1970; Turner, 1985; Sim, 1985; Parnas, 1986; Applegate, Konsynski, & Nunamaker, 1986; Lewis, 1988; Ughanwa, 1988; Twigg, 1995; Zanella & Gubian, 1996; Eastman C. M., 1996; Saad & Maher, 1996; Wright, 1997; Mcdermott, 2003; Peng & Trappey, 1999; Owens, 2000; Chua & Tyagi, 2001; Reid, Culverhouse, Jagodzinski, Parsons, & Burningham, 2000; Goonetillake, Carnduff, & Gray, 2002; Nagl, Westfechtel, & Schneider, 2003; Mozota, 2003a; Choo, Hammond, Tommelein, Austine, & Ballardd, 2003; Joshua, 2004; Conley, 2004; Rieple, 2004; Andersen, Nycyk, Jolly, & Radcliffe, 2004; Marquardt & Nagl, 2004; Heller, Jager, Schluter, Schneider, & Westfechtel, 2004; Moody, 2005; Siddiqui, 2005; Moody, 2005; Andersen, Nycyk, Jolly, & Radcliffe, 2005; Sanchez, 2006; Owen, 2006; Mozota, 2006; Baxter, et al., 2008; Mozota & Kim, 2009; Kestle, Remote Site Design Management, 2009; Mozota, 2010; Acklin, 2011; Ping, Keung, & Ramanathan, 2011; Dutta, 2013a).

Today's fast paced competition needs engineering designs to be optimized but this optimization can only be managed through an *efficient design management system that limits the optimization in a particular discipline based on its dependant disciplines' limitations* in a multidisciplinary design environment (Rodriguez, Renaud, Wujek, & Tappeta, 2000). Today's sophisticated "state of the art" CAD systems require much more proactive design management system than actually practiced (Malhotra, Heine, & Grover, 2001). *Management functionality that enables experimenting with a dynamic environment that supports decision making & management of future outcomes, rather than dictating well designed activities*, is the need of the hour (Artto, Lehtonen, & Saranen, 2001).

Balanced Scorecard is a management instrument developed to measure business performance, originally created at Analog Devices in the 1980s, that be used to assess activity performance of an organization based on four perspectives, namely (i) financial, (ii) customer, (iii) internal business and (iv) innovation and learning (Kaplan & Norton, 1996; Wong, Lam, & Chan, 2009). The problems of design quality commonly arise due to divergent goals between the client and the design team who have different aspirations and perceptions (Colander, 2003). Wong, Lam, & Chan (2009) showed how design objectives, optimized by using balanced scorecard approach using *the four typical design objectives, i.e. Aesthetics, Functionality, Buildability and Economics,* can successfully manage the conflicts between the client and the design team in order to *ensure the optimum product quality* in building design industry (Wong, Lam, & Chan, 2009).

The "entire cycle of design management consists of six phases" (Howard, Culley, & Dekoninck, 2008; Dutta, Findings from a Review of Existing Approaches and Models of Engineering Design Management, 2013; Dutta, A Theoretical Model of Innovation Integrated Engineering Design Management, 2013) discussed earlier & "each phase consists of *two main interfering sectors – 1. the Design Product Engineering Side consisting mostly of the actual engineering design execution activities like CAD, Computer Aided Engineering (CAE), design optimization & product quality assurance, and, 2. the Design Process Side consisting mostly of the management of the associated design activities of the design product* like design knowledge management, design cycle sequencing-controlling-monitoring, conflict management, interdisciplinary management, innovation integration, feedback integration, non-value adding activities' identification & elimination, design change order management, rework minimization & design project work management" (Visser, 1996; Lee, Sause, & Hong, 1998; Swink, 2000; Dutta, 2013a, 2013b).

Sheu & Chen (2007) researched on the product side of design management to propose a framework facilitating feedback-guided backward design engineering analysis & cross-functional design (Sheu & Chen, 2007) but does not address the problems on the process side like innovation integration, non-value adding activities' identification & elimination, change order management, etc. highlighted by other researchers discussed earlier. Plant Design Management

System or PDMS® is one of the most widely used leading CAD tools for modeling plants pertaining to a wide range of industries. But *it caters to only the product side & not to the process side of design management* (AVEVA, 2012). *That too, on the product side it caters specifically to the creation & management of drawings & databases whereas the creation & management of the engineering design analyses are left for the design manager through manual or other CAD methods* (AVEVA, 2012). Plant Design System or PDS® is another software similar to PDMS® (Intergraph, 2012). Other popular CAD softwares such as AutoCAD®, Autodesk Inventor®, Solidworks®, Pro/Engineer®, AutoCAD®, Autodesk Streamline®, etc. do not offer any tool for real-time management of the collaborative design process (Wang, Tang, Song, & Jiang, 2009). Wang et al. built a software based Collaborative Design Process Model (CDPM) that interacts with the CAD software & other communication softwares to facilitate data management, collaboration, design changes and conflict management but does not, however, cater to the other problems on the process side like innovation integration and non-value adding activities' identification & elimination highlighted by other researchers discussed earlier. Acklin (2009) developed a Design-Driven Innovation Process Model that systematically integrates innovation into the design process but the model has not been validated (Acklin, 2009). Acklin's model also does not cater to the design manager's problems of multidisciplinary collaboration, non-value adding activities, reworks, data management & conflicts observed by other researchers discussed earlier. Some researchers built a process model that aids innovation in conceptual design but does not cater to the other stages of the design cycle and the other problems of design management (Li, Li, Wang, & Liu, 2010). Research has recognized the importance of *design audits* for design product quality assurance (Sung & You, 2007). Researchers built a tool named TracED that allows the capturing & tracing of the engineering design processes limited only to the software & chemical engineering design domains (Roldan, Gonnet, & Leone, 2010). Taylor (2007) found that for combating design errors a combination of more than one analysis type is more effective like *Hazard Identification & Operability (HAZOP) Studies, Design & Drawing Reviews in multiple stages and Mechanical Audits* (Taylor J. R., 2007).

Design engineers rate technical work as more satisfying than non-technical social work but ironically, research suggests that 50% or more of each design engineer's time is used for work of a less or non-technical nature especially project management involving motivation, communication & leadership (Robinson, How design engineers spend their time: Job content and task satisfaction, 2012). Researches also showed that design engineers are aware of this increasing importance & prevalence of non-technical work over technical work and this is a cause of tension for design engineers which in turn reduces their job satisfaction & this calls for an efficient & effective management system that aids the design engineers in their increasingly prevalent non-technical work & project management so as to combat their falling satisfaction levels (Robinson, 2012).

From the reviews of the existing literatures, it is seen that many researches have concentrated either upon *only some aspects of the product side* (Pahl, Beitz, & (Ed.) Wallace, 1984; Beames, 1987; French, 1992; Beitz, 1994; Karcanias, 1995; Pahl, Beitz, & (Ed.) Wallace, 1996; Brunettia & Golob, 2000; Jagodzinski, Reid, Culverhouse, Parsons, & Phillips, 2000; Zha & Du, 2002; Roy & Bharadwaj, 2002; Gabbar, Suzuki, & Shimada, 2003; Su, Chen, & Lin, 2003; Halachmi, Simon, Guetta, & Hallerman, 2005; Yang & Han, 2006; Tan & Vonderembse, 2006; Sung & You, 2007; Taylor J. R., 2007; Sheu & Chen, 2007; Young, 2008; Shen, Hao, & Li, 2008; Roy, Hinduja, & Teti, 2008; Sung, et al., 2009; Bracewell, Wallace, Moss, & Knott, 2009; Dellino, Lino, Meloni, & Rizzo, 2009; Sakao, Shimomura, Sundin, & Comstock, 2009; Bock, Zha, Suh, & Lee, 2010; Smith & Ierapepritou, 2011; Linfeng, Qiang, & Lin, 2011; Hsiao, Hsu, & Lee, 2012; Chen, Gao, Yang, & Zhang, 2012; Adhikari, Aste, & Manfren, 2012;

Xiaoyan, 2012; McIntosh, et al., 2012; Du, Mo, Li, & Li, 2012; Raine & Walker, n.d.; AVEVA, 2012; Intergraph, 2012a) or *only some aspects of the process side* (Harary, Jessop, Stringer, & Luckman, 1965; Taylor & Moore, 1980; Steward, 1981; Heerema & Hedel, 1983; Bretschneider & Lagger, 1992; AitSahlia, Johnson, & Will, 1995; Brown, et al., 1995; Dearnley & Smith, 1995; Kiwan & Munns, 1996; Shah, Jean, Urban, Bliznakov, & Rogers, 1996; Case & Lu, 1996; Wagner, Castanotto, & Goldberg, 1997; Parent, 1997; Kim, Liebich, & Maver, 1997; Jokinen, 1997; Busby, 1998; Smith & Eppinger, 1998; Dong & Agogino, 1998; Chen, Frame, & Maver, 1998; Kalay, Khemlani, & Choi, 1998; Dowlatshahi & Nagaraj, 1998; Willaert, Graaf, & Minderhoud, 1998; Moffat, 1998; Pena-Mora & Hussein, 1998; Martino, Falcidieno, & Habinger, 1998; Peng & Trappey, 1999; Yair, Tomes, & Press, 1999; Atman, Chimka, Bursic, & Nachtmann, 1999; Herder & Weijnen, 1999; Hurst, 1999; Rogers & Salas, 1999; Reid, Culverhouse, Jagodzinski, Parsons, & Burningham, 2000; Miles, Gray, Carnduff, Santoyridis, & Faulconbridge, 2000; Lloyd, 2000; Moreau & Back, 2000; Baird, Moore, & Jagodzinski, 2000; Owens, 2000; Rodriguez, Renaud, Wujek, & Tappeta, 2000; Tiwana & Ramesh, 2001; Artto, Lehtonen, & Saranen, 2001; Concheri & Milanese, 2001; Wang, Shen, Xie, Neelamkavil, & Pardasani, 2002; Hicks, Culley, Allen, & Mullineux, 2002; Wang, Mills, & Devarajan, 2002; Hislop, Lacroix, & Moeller, 2002; Bertola & Teixeira, 2003; Rouibah & Caskey, 2003; Koh, Ha, Kim, Rho, & Lee, 2003; Hsu & Hwang, 2004; Lowe, McMahon, & Culley, 2004; Merlo & Girard, 2004; Carnduff & Goonetillake, 2004; Wu & Sarma, 2004; Chen, Chen, Wang, Chu, & Tsai, 2005; Wu & Sarma, 2005; Wu, Hsieh, & Cheng, 2005; Liao, 2005; Ozkaya & Akin, 2006; Hicks, Culley, & McMahon, 2006; Girard & Robin, 2006; Lombard & Yesilbas, 2006; Sung & You, 2007; Robin, Rose, & Girard, 2007; Zdrahal, Mulholland, Valasek, & Bernardi, 2007; Baxter, et al., 2008; Shiau & Wee, 2008; Bordoloi & Guerrero, 2008; Zeng, 2008; Serror, Inoue, Adachi, & Fujino, 2008; Giess, Wild, & McMahon, 2008; Nunes, Santoro, & Borges, 2009; Wu J.-H. , 2009; Eilouti, 2009; Ahlemann, 2009; Mahdjoub, Monticolo, Gomes, & Sagot, 2010; Pirro, Mastroianni, & Talia, 2010; Kocar & Akgunduz, 2010; Bai, Gao, Tang, Liu, & Guo, 2010; Pitiot, ThierryCoudert, Geneste, & Baron, 2010; Tang, Zhu, Tang, Xu, & He, 2010; Shen, et al., 2010; Bowen, Edwards, Cattell, & Jay, 2010; Chua & Hossain, 2011; Berends, Reymen, L., & Eindhoven, 2011; Eastman & Shirley, n.d.; Kim & Kim, 2011; Luo, Shen, Fan, & Xue, 2011; Lau, 2011; Park, 2011; Xu, Houssin, Caillaud, & Gardoni, 2011; Liu, Li, Pan, & Li, 2011; Artto, Kulvik, Poskela, & Turkulainen, 2011; Lehoux, Hivon, Williams-Jones, & Urbach, 2011; Dongmin, Dachao, Yuchun, & Hong, 2012; Mukhtar, Ismail, & Yahya, 2012; Hermans, Naber, & Enserink, 2012; Kumar & Yao, 2012; Quintana, Rivest, Pellerin, & Kheddouci, 2012; Wang, Johnson, & Bracewell, 2012) of design management, not holistically.

The *need for a design management model that fully covers the entire design management cycle including the product as well as the process sides has been recognized by design engineers & researchers worldwide for quite some time now* (Royce, 1970; Turner, 1985; Ughanwa, 1988; Wallace & Burgess, 1995; Sharpe, 1995; Twigg, 1995; Zanella & Gubian, 1996; Visser, 1996; Ogunlana, Lim, & Saeed, 1998; Lee, Sause, & Hong, 1998; Chapman, 1998; Smith & Morrow, 1999; Swink, 2000; Reid, Culverhouse, Jagodzinski, Parsons, & Burningham, 2000; Malhotra, Heine, & Grover, 2001; Pike & Chaney, 2001; Lang, Dickinson, & Buchal, 2002; Kestle & London, 2002; Choo, Hammond, Tommelein, Austine, & Ballardd, 2003; Heller & Westfechtel, 2003; Nagl, Westfechtel, & Schneider, 2003; Andersen, Nycyk, Jolly, & Radcliffe, 2004; Heller, Jager, Schluter, Schneider, & Westfechtel, 2004; Gabbar, Aoyama, & Naka, 2004; Lardeur & Longueville, 2004; Liu, Tang, & Frazer, 2004; Marquardt & Nagl, 2004; Andersen, Nycyk, Jolly, & Radcliffe, 2005; Cho & Eppinger, 2005; Seshasai, Gupta, & Kumar, 2005; Pektas & Pultar, 2006; Klashner & Sabet, 2007; Mozota & Kim, 2009; Girard & Doumeingts, 2010; Parent, 1997; Tzortzopoulos, Cooper, Chan, & Kagioglou, 2006; Vermaas & Dorst, 2007; Gonnet, Henning, & Leone, 2007; Acklin & Hugentobler, 2007; Chiva & Alegre, 2007; Danilovic & Browning, 2007; Young, 2008; Wang, Tang, Song, & Jiang, 2009; Manzini & Bindi, 2009; Juuti & Lehtonen, 2010) (Pitiot, ThierryCoudert, Geneste, & Baron, 2010; Roldan, Gonnet, & Leone, 2010; Charnley, Lemon, & Evans, 2011; Tonkinwise, 2011; Ping, Keung, & Ramanathan, 2011; Cipriani, M.Wieland, M.Grobmann, & D.Nicklas, 2011). However, as it has been seen in the preceding discussions, *holistic design management models have so far been built for the Architecture, Civil, Construction, Electronics, Mechatronics, Aerospace, Transportation / Automotive, Medical, Software, Chemical Engineering Design Industries only*. From the preceding discussions it has also been seen that a few models have been built that are applicable to any engineering design management but do not solve the *design manager's problems of innovation integration and non-value adding activities' identification & elimination*. The integration of the product side involving tools & the process side involving management towards a fuller model of design management that is efficient yet flexible, *is still lacking*, inspite of the fact that *without integration, data and information needs to be manually transferred between tools adding to the cognitive load of design engineers, disrupting creative thought processes and leading to the possibility of misinterpretation or loss of design information* (Lang, Dickinson, & Buchal, 2002).

Design Management has three main ranges or governing levels –

i. *Strategic Design Management,*
ii. *Tactical Design Management &*
iii. *Operational Design Management* (Mozota, 2003b; Sun, Williams, & Evans, 2011).

The three governing levels of design management run on both sides (Product Side and Process Side discussed earlier) through each of the six phases of the design management cycle. The broad business goals for each phase and the piping design management philosophy are created in Strategic Design Management level and flow to Tactical Design Management level. Resources required for piping design and management, conducive conditions and implementation logics flow from Tactical Design Management level to Operational Design Management level. The practical implementation consisting of the actual design of the piping system and its management is controlled in the Operational Design Management level and hence this Operational Design Management level also produces necessary improvement feedbacks to the higher governing levels besides yielding the optimal design output, thus completing the piping design management cycle for that phase on each side (Visser, 1996; Lee, Sause, & Hong, 1998; Swink, 2000; Mozota, 2003b; Conley, 2004; Howard, Culley, & Dekoninck, 2008; Dutta, 2013a).

Conley (2004) illustrated how design expertise can be effectively managed to produce an innovative solution through three layers –

a. *Enabling Technology Layer,*
b. *Solution Layer and*
c. *Interface Layer* (Conley, 2004).

Sanchez's (2006) research stressed the integration of design & management at the strategic level (Sanchez, 2006). Acklin & Hugentobler's (2007) research into the issue of innovation integration in design management of SMEs only at the Strategic level finds that design is not yet an integral part of company's mindset which can be addressed by an innovation integrated model of design management (Acklin & Hugentobler, 2007). Thurston-Chartraw's (2006) research, besides supporting innovation integration at the strategic level, also highlights the need to integrate innovation into the tactical level (Thurston-Chartraw, 2006). There are other researchers who highlighted the need to *integrate innovation systematically into all the levels of design management* (Willaert, Graaf, & Minderhoud, 1998; Bertola & Teixeira, 2003; Salter & Gann, 2003; Rieple, 2004) as chronicled in the preceding paragraphs.

"The case study method is a favoured method to study practices of design management" (Svengren, 1993) because the research inquiries include a concern for how to integrate design with other business functions, which is a process of change" (Svengren, 1993; Kothari, 2004) and enables an in-depth, and detailed examination of a subject of study (the case) relevant under contextual conditions in order to reach the basic causal relations (Kothari, 2004). Green, Kennedy, & McGown (2002) have researched into the existing four case study based research methods in engineering design namely Protocol Studies, Ethnographic Observation, Historical Analysis & Experiental Analysis and have found that a Multi-Method research approach, that complementarily uses the four methods as per suitability, is best in terms of interpretability & recognition of research (Green, Kennedy, & McGown, 2002). Protocol Studies are concerned with constraining or equalizing variables of the research equation (Dorst, 1995). When designers work for real such rational constructs do not apply leading to the research being less representative of the actual design process (Dwarakanath & Wallace, 1995; Green, Kennedy, & McGown, 2002). With the growing recent recognition of engineering as essentially a human activity, Ethnographic Studies, wherein the researcher gains access to companies and working as designers or with designers the researcher gets an inside view of their activities, prove to be more useful in helping to understand how and why design happens (Wallace & Hales, 1989; Kennedy, 1997; Green, Kennedy, & McGown, 2002). Historical Analysis is used for comparing new design products to past one or learning from past design (Green, Kennedy, & McGown, 2002). Some design researchers have used Experiental Analysis to draw on their own designing experiences to explain the aspects of the design process (Green, Kennedy, & McGown, 2002). French studied engineering design from product side "through his experience of design" (French, 1992). Pahl and Beitz also put up a similar study (Pahl, Beitz, & (Ed.) 1984). "Design researchers are also rightly concerned about the lack of acceptance of their ideas by practising designers" (Cross, 1993; Beitz, 1994; Green, Kennedy, & McGown, 2002). "By *involving designers in the research as* *equal partners* it is more likely that the outcome of the research will be taken up because of the shared ownership of the knowledge produced by the research" (Green, Kennedy, & McGown, 2002). A Multi-Method research approach combines the advantages of the four methods complementarily to negate the disadvantages of each, thus leading to enhanced recognition of the research (Green, Kennedy, & McGown, 2002). In the study of design process, the adoption of a *qualitative and inductive approach* enables the collection of a vast amount of primary data without any predetermined judgements as to what factors are most pertinent (Charnley, Lemon, & Evans, 2011).

Design thinking & corresponding *design activities in different industries in differing situations not only have significant similarities but also have crucial differences* (Visser, 2009). For example - design activity in all industries involes problem solving, reuse of knowledge, etc. thus having similar traits; but Architects use ad hoc strategies to integrate partial solutions into global ones, whereas Electronic & Mechanical Design Engineers use predetermined procedures to integrate interactions between parts of a VLSI circuit or mechanical assembly respectively, etc. thus having crucial differences (Akin, 2001; Visser, 2009). So the previously discussed *design management studies, undertaken in other industries, are uncertain in terms of their applicability to the oil & gas industries* and there has been no research on their applicability to the oil & gas industry. Some scholars identified through research that Design Management roles & practices vary from country to country, region to region and they recommended *region-specific design management* remits (Sun, Williams, & Evans, 2011). For example, although design management as a subject is both academically prevalent in the UK & the USA, however, whereas spotty applications of existing design management knowledge can be found in the UK but existing design management knowledge is not being out to practice in the US companies; further, the existing design management activities (for example, design approach, workflow management, design knowledge management, etc.)

significantly vary from US to UK to China – while US follows a restrictive (design by rule/analysis) approach, UK follows a risk based (safety case) approach whereas China follows both restrictive as well as risk based approaches depending on their particular Client's requirement, thus, rendering the design management activities differ significantly from country to country (Bruce, 1998; Jonson, 2006; Biddle, 2007; Chen et al., 2007; HSE, 2008; Hugentobler, 2008; Patrick, 2008; Ashton and Ye Deng, 2008; O'Brien et al., 2009; ASME 2013, 2014; BSI, 2010, 2014; DS, 2010; Sun, Williams, & Evans, 2011), So the previously discussed *design management studies, undertaken elsewhere, are uncertain in terms of their applicability to India and in India no research has been done in engineering design management*. Sun et al. (2011) also defined design management as the "management of the interface between design and the other stakeholders within the industry" and identified five key design management roles – Line Management of Design Teams, Management of Knowledge Input, Management of Design Output, Managing the Interface with Substitute Design Products, and Managing & Redefining Entry Barriers. Sun, et al. also stressed the growing & *indispensable need for a comprehensive design management system/model, however no research has been done on engineering design management in India*.

The issues that have emerged from the preceding reviews of existing literatures on multidisciplinary engineering design management are as follows in Emergence E:

Emergence: E

1. *An integrated management model for managing engineering design is indispensably needed* to aid design engineers in their design management decisions and *to sustain the competitive edge* of the company (Turner, 1985; Ughanwa, 1988; Wallace & Burgess, 1995; Kiwan & Munns, 1996;

Lee, Sause, & Hong, 1998; Chua & Tyagi, 2001; Owen, 2006; Mozota, 2006; Mozota & Kim, 2009; Sun, Williams, & Evans, 2011) *and hence the companies who do not have effective design management practices/models are much less successful in business that the ones having it* (Bruce, Cooper, & Vazquez, 1999). Effective management of engineering design is also needed *to increase job satisfaction of design engineers* (Ahire & Dreyfus, 2000; Rieple, 2004; Robinson, 2012).

2. Design Management has three levels - *Strategic Design Management, Tactical Design Management & Operational Design Management* (Mozota, 2003b; Sun, Williams, & Evans, 2011). In each level, design expertise can be effectively managed to produce an innovative solution through three layers – *Enabling Technology Layer, Solution Layer and Interface Layer* (Conley, 2004).

3. The entire cycle of engineering design management consists of six phases (Howard, Culley, & Dekoninck, 2008) & each phase consists of has *two interfering sides – the Design Product Engineering Side & the Design Process Side* (Visser, 1996; Lee, Sause, & Hong, 1998; Swink, 2000).

4. Many researchers have focused only on the issues of the product side. The *issues of design management on the product side* are – (i) design philosophy needs to be *objective* instead of being subjective (Woudhuysen, 2006), (ii) designers need to *exploit the positive side of uncertainty* rather than focusing just on the negative side (Neufville, 2004), (iii) *design optimization needs to be based on the limitations of its dependant disciplines* (Rodriguez, Renaud, Wujek, & Tappeta, 2000), (iv) judicious management of the *four design objectives of Aesthetics, Functionality, Buildability and Economics between the client and the design team, that is needed in order to ensure optimum product quality*

(Wong, Lam, & Chan, 2009) and (v) effective *combating of design errors through a combination of more than one analysis type* like Hazard Identification & Operability (HAZOP) Studies, Design & Drawing Reviews in multiple stages and Mechanical Audits (Taylor J. R., 2007).

5. Many researchers have focused only on the issues of the process side. *The issues of design management on the process side* are – (i) *design knowledge management* (Heerema & Hedel, 1983; Kiwan & Munns, 1996; Zanella & Gubian, 1996; Jokinen, 1997; Kim, Liebich, & Maver, 1997; Martino, Falcidieno, & Habinger, 1998; Herder & Weijnen, 1999; Miles, Gray, Carnduff, Santoyridis, & Faulconbridge, 2000), (ii) *management of the six phases namely Establishing a Need Phase, Analysis of Task Phase, Conceptual Design Phase, Embodiment Design Phase, Detailed Design Phase, Implementation Phase, of the design cycle*, through sequencing-controlling-monitoring (Visser, 1996; Lee, Sause, & Hong, 1998; Rogers & Salas, 1999; Howard, Culley, & Dekoninck, 2008), (iii) *conflict management* & collaborative resolution by shared understanding & treating assertions as facts (Case & Lu, 1996; Wang, Shen, Xie, Neelamkavil, & Pardasani, 2002; Pena-Mora & Hussein, 1998; Kleinsmann & Valkenburg, 2008), (iv) *interdisciplinary management* involving collaborative coordination & team integration (Reid, Culverhouse, Jagodzinski, Parsons, & Burningham, 2000; Liu, Tang, & Frazer, 2004), (v) *systematic innovation integration* in all the three management levels of design management using 4 characteristics of Explicitness, Novelty, Importance & Usability (Willaert, Graaf, & Minderhoud, 1998; Swink, 2000; Salter & Gann, 2003; Bertola & Teixeira, 2003; Rieple, 2004; Xu, Houssin, Caillaud, & Gardoni, 2011) through three management layers – Enabling Technology Layer, Solution Layer and Interface Layer (Conley, 2004), (vi) dynamic *bi-directional feedback integration* (Dearnley & Smith, 1995; Zanella & Gubian, 1996;

Busby, 1998; Sheu & Chen, 2007), (vii) *non-value adding activities' identification & elimination* (Chua & Tyagi, 2001), (viii) *design change order management* (Wright, 1997; Ogunlana, Lim, & Saeed, 1998; Wang, Tang, Song, & Jiang, 2009), (ix) *rework minimization* (Ahire & Dreyfus, 2000; Chua & Tyagi, 2001), (x) *effective communication* that is needed between the client & the design team, which can be facilitated through a question-answering mechanism consisting of different questions on 5 main categories – Elaboration, Enablement, Validation-Current-Model, Validation-Future-Model & Clarification (Parent, 1997) and (xi) *design project management maintaining a balance between top-down & bottom-up management* methods to enable more effective design management products (Owens, 2000; Dias, Subrahmanian, & Monarch, 2003).

6. Popular CAD softwares such as PDMS®, AutoCAD®, Autodesk Inventor®, Solidworks®, Pro/Engineer®, PDS®, AutoCAD®, Autodesk Streamline®, etc. cater only to the product side and do not offer any tool for real-time holistic management of the design process (Wang, Tang, Song, & Jiang, 2009; Intergraph, 2012b; AVEVA, 2012).

7. Integrated design management frameworks & models, that have so far been built, are applicable only to the Architecture, Civil, Construction, Electronics, Mechatronics, Aerospace, Transportation / Automotive, Medical, Software, Chemical Engineering Design Industries (Wallace & Burgess, 1995; Kiwan & Munns, 1996; Case & Lu, 1996; Zanella & Gubian, 1996; Lee, Sause, & Hong, 1998; Chua & Tyagi, 2001; Kestle & London, 2002; Liu, Tang, & Frazer, 2004; Roldan, Gonnet, & Leone, 2010; Komoto & Tomiyama, 2012). For the oil & gas industry, no integrated multidisciplinary engineering design management model can be found that caters to the issues of the product & the process sides.

8. A study of the design process, employing a *qualitative and inductive approach* enables the collection of a vast amount of primary data without any predetermined judgements as to what factors are most pertinent (Charnley, Lemon, & Evans, 2011). Ethnographic Studies, wherein the researcher gains access to companies and working as designers or with designers the researcher gets an inside view of their activities, have been found to be more useful in helping to understand how and why design happens, and teamwork in design teams (Wallace & Hales, 1989; Kennedy, 1997; Baird, Moore, & Jagodzinski, 2000; Green, Kennedy, & McGown, 2002). Researchers have found that the qualitative case study method is a favoured method to study & analyze practices of design management (Svengren, 1993) and a Multi-Method research approach, that complementarily uses the four case study based methods, namely Protocol Studies, Ethnographic Observation, Historical Analysis & Experiental Analysis, as per suitability, is best in terms of interpretability & recognition of research (Green, Kennedy, & McGown, 2002).

9. Design thinking & corresponding *design activities in different industries in differing situations not only have significant similarities but also have crucial differences* (Visser, 2009).

10. Design Management roles & practices vary from country to country, region to region (Sun, Williams, & Evans, 2011).

II. Existing Researches/Models/Practices in Piping Engineering Design Management:

Piping Engineering Design is a domain of mechanical engineering design (Tsai, Yang, & Liao, 2011) that studies the efficient transport of fluid or pressure from one point to another (ASME, 2014) and hence, naturally consists of six phases (Howard, Culley, & Dekoninck, 2008) where each phase consists of a

a. Design Product Engineering Side, &

b. Design Process Side as have been discussed for multidisciplinary engineering design management in the preceding paragraphs. Subsequently, the earlier discussed design management problems of multidisciplinary engineering design management are also naturally inherent in piping engineering design management. The criticality of piping design engineering management lies in the fact that piping consumes *more than 40% of any plant's design engineering activities* (Sheremetov, Batyrshin, Chi, & Rosas, 2008). "Piping is popularly compared to the arteries in human body and, the adage that piping study is 'half science and half art' is true, the art part is visualization and creativity while the science part refers to following the established norms" (Prasad, 2009; Dutta, 2013a, 2013b).

The preceding discussed multidisciplinary "design management models that have so far been built, are applicable for the Architecture, Civil, Construction, Electronics, Mechatronics, Aerospace, Transportation / Automotive, Medical, Software, Chemical Engineering Design Industries only. And, *since design thinking & corresponding design activities in different industries in differing situations not only have significant_similarities but also have crucial differences* (Visser, 2009)", therfore the previously discussed *design management studies, undertaken in other industries, are uncertain in terms of their applicability to the oil & gas industries* and there has been no research on their applicability to the oil & gas industry (Dutta, 2013a, 2013b).

Guzy (1987) undertook a research on dynamic load capacity testing of piping in the nuclear industry (Guzy, 1987). Some researchers developed an integrated piping design system focusing purely on the product side of only small bore piping design applicable only to the nuclear industry (Mo, 1994). Some other undertook a similar research but applicable to all bore piping and built a Nuclear Piping Integrity Expert System (NPIES) focusing purely on the product side of piping design applicable only to the nuclear industry (Kim, Suh, Jun, Park, & Choi, 1997). Fleming (2004) focused on the product side & applied Markov models for predicting nuclear industry piping reliability (Fleming, 2004). All of these researchers have been focused on the product side of engineering design from purely an engineering point of view, without any consideration for the managerial aspects in design management, that too for industries other than oil & gas outside India but design management varies from industry to industry (Visser, 2009) as well as country to country (Sun, Williams, & Evans, 2011) and the previous researchers neither focussed on design management in oil & gas industry nor on design management in India.

Researchers found that piping design is one of the most significant cost drivers in any plant but piping engineering management methods are still imprecise necessitating a project management type model for piping (Pulkkinen, Vainio-Mattila, & Riitahuhta, 1997). These researchers built a model for capturing the piping design process applicable only to the power plant industry (Pulkkinen, Vainio-Mattila, & Riitahuhta, 1997). Some other scholars focused purely on one of the aspects of the product side of piping design, the optimal shortest route problem and found that by using a power multiplication method subsequent to basic CAD system an optimally short piping route can be obtained in a power plant (Yamada & Teraoka, 1998).

Revesz focused on the stress aspect of the product engineering side of piping design management & developed Piping Analysis and Interactive Design (PAID) software that do not cater to the management of the process side (Revesz, 1985). Water hammer produces large dynamic forces that damage piping. Some researchers focused on this aspect of piping engineering to recommend the influencing of fluid dynamic conditions & other dynamic variations to minimize the effects (Gillessen & Lange, 1988). Some scholars developed Integrity Assessment Expert System of In-service Pressure Piping Containing Flaws (IAESPP-SINTAP) that assesses piping defects based of computing stress intensification factors (Lin & Xie, 2006). IAESPP-SINTAP, like its predecessors, caters only to one aspect of piping design engineering and not to the holistic (integrated product & process sides) management of piping engineering design. Some other researchers developed a method to aid the designer develop a 3D piping model piping applicable to ship design focused purely on the product engineering side of piping design (Roh, Lee, & Choi, 2007).

The product side of piping design engineering has two main components – 1. the Design Drawing Part (for e.g. developing the 2D plans, elevations, bill of quantities or the 3D model of the plant, etc.) and 2. The Design Engineering Part (for e.g. doing the calculations for deciding upon the pipe thicknesses, materials, stress effects, flexibilities, supports, etc.) for which respective softwares are there (Sheremetov, Batyrshin, Chi, & Rosas, 2008; Wang, Tang, Song, & Jiang, 2009), as follows –

1. *Design Drawing Softwares* - PDMS®, AutoCAD®, Autodesk Inventor®, Solidworks®, Pro/Engineer®, PDS®, AutoCAD®, Autodesk Streamline®, etc. (Wang, Tang, Song, & Jiang, 2009; Intergraph, 2012b; AVEVA, 2012).

2. *Design Engineering Softwares* - Caesar II®, CAEPIPE®, ROHR2®, AutoPIPE®, PetroPipe®, etc. (Sheremetov, Batyrshin, Chi, & Rosas, 2008; Sigma, 2012; Bentley, 2012; Solutions, 2012; PetroStreet, 2012; Intergraph, 2012a).

The latest software tools for Part 1 do not have the capabilities of those of Part 2 and vice-versa, & this hampers of collaboration & concurrency of the product development process leading to increased human errors & man-hours (Sheremetov, Batyrshin, Chi, & Rosas, 2008). In order to combat this problem, Sheremetov et al. (2008) built a framework for stress-layout collaborative engineering design of oil & gas industry piping systems. This framework facilitates seamless data exchange between the two parts by employing an interoperability architecture thus facilitating the needs of the piping design engineers. Sheremetov et al. (2008) however focused only on the product side of piping design from an engineering point of view and hence did not take care of the *management problems troubling the Design Managers on both the product as well as the process sides of piping engineering design management*, as discussed in the preceding paragraphs.

Some researchers concentrated on the piping network design optimization of a geothermal heating system (Yildirim, Toksoy, & Gokcen, 2010) while some others studied the standard inspections techniques in vogue for cross-country pipeline's integrity (Kishawy & Gabbar, 2010) but both the researches concentrated upon the piping from a purely engineering point of view. Tsai et al. (2011) showed *that increasing the concurrency of the conceptual stages through a management model can reduce the project duration as well as the cost* & built a model for foam firefighting piping system for the construction industry (Tsai, Yang, & Liao, 2011).

Plant Design Management System (PDMS®) is the most widely used popular software in its category, but can be used only for the Design Drawing Part (Part 1 discussed earlier) on the product engineering side of piping design (Parisher & Rhea, 2012; AVEVA, 2012) just like other drawing softwares - PDS® (Intergraph, Intergraph PDS, 2012), AutoCAD®, Autodesk Inventor®, Solidworks®, Pro/Engineer®, AutoCAD®, Autodesk Streamline®, etc. (Wang, Tang, Song, & Jiang, 2009).

Caesar II® is the most widely used popular software in its category, but can be used only for the Design Engineering Part (Part 2 discussed earlier) on the product engineering side of piping design (Sheremetov, Batyrshin, Chi, & Rosas, 2008; Intergraph, 2012a) just like other piping engineering softwares - CAEPIPE®, ROHR2®, AutoPIPE®, PetroPipe®, etc. (Sheremetov, Batyrshin, Chi, & Rosas, 2008; Sigma, 2012; Bentley, 2012; Solutions, 2012; PetroStreet, 2012).

As it has been seen from the preceding reviews of available existing literatures, The existing studies did *neither focus on the management aspects present in both the product sides and the process sides nor into any integrated model for the complete cycle that caters to the management issues of the product as well as the process sides*. However, previous studies have established that *design management roles, practices & activities significantly vary from industry to industry* (Visser, 2009) *and from country to country* (Sun, Williams, & Evans, 2011). Further, the previous studies neither throw a*ny light on the oil & gas industry nor on the design management issues*. From the existing literature review, it has been found that no research has focused on whether there are any issues plaguing the management of engineering design in India. The existing studies have identified issues plaguing engineering design management worldwide in other industries & outside India. Moreover, design management practices vary from industry to industry and from country to country. Therefore, the *applicability of those identified issues to the Indian oil & gas context is uncertain*. No study has focussed on their applicability to either the oil & gas industry or on their applicability to India. Moreover, previous researchers have stressed the growing & indispensable need for a *comprehensive design management model* and in India no research has focussed on engineering design management.

Piping engineering being under the domain of mechanical engineering design (Tsai, Yang, & Liao, 2011) naturally has the same management problems on the product & the process sides as discussed in Emergence: E points 4 & 5 earlier. Also *piping design management has three levels - Strategic Design Management, Tactical Design Management & Operational Design Management* (Mozota, 2003a, 2003b, 2009; Sun, Williams, & Evans, 2011) and in each level, design expertise can be effectively managed to produce an innovative solution through *three layers – Enabling Technology Layer, Solution Layer and Interface Layer* (Conley, 2004).

The researcher, a mechanical engineer, on working in the piping engineering design departments of different multinational & Fortune 100 companies during the last ten plus years, have also *experientially observed all the preceding discussed findings (especially the issues/challenges in Emergence: E points 1, 4 & 5) from the existing literatures, plaguing the management of piping engineering design in actual practice, and have deeply felt the indispensable need for an integrated management model for efficiently managing the design product engineering side as well as the design process side.* As such, the researcher's experience reinforces the earlier observations from the available existing literatures. Hence, the researcher aspired to use the knowledge substantiated by scholars discussed in the earlier Emergence: E points and the research methods enlightened by Charnley et al. (2011) discussed in the Emergence: E point 8, to understand the existing oil & gas piping design management practices in India, identify the areas of improvements and build an ***Integrated Piping Engineering Design Management Model for Oil & Gas Industry in India*** because design improves the competitive edge of a country in international competitions (Ughanwa et al., 1988; Mozota, 2003a, 2003b; Dutta, 2013a).

3.2 Conceptual Frames

The preceding literature review discussions formed the conceptual frames for this study on the various issues plaguing the piping engineering design management cycle. The aphoristic *key highlights* are as follows.

Previous researchers have established that design management cycle comprises of *Three Governing Levels* –

i. Strategic Design Management,

ii. Tactical Design Management &

iii. Operational Design Management (Mozota, 2003a, 2003b, 2009; Sun et al., 2011)

and some other researchers have established that *at Each Level*, design expertise can be effectively managed to produce an innovative solution through *Three Layers* –

a. Enabling Technology Layer,

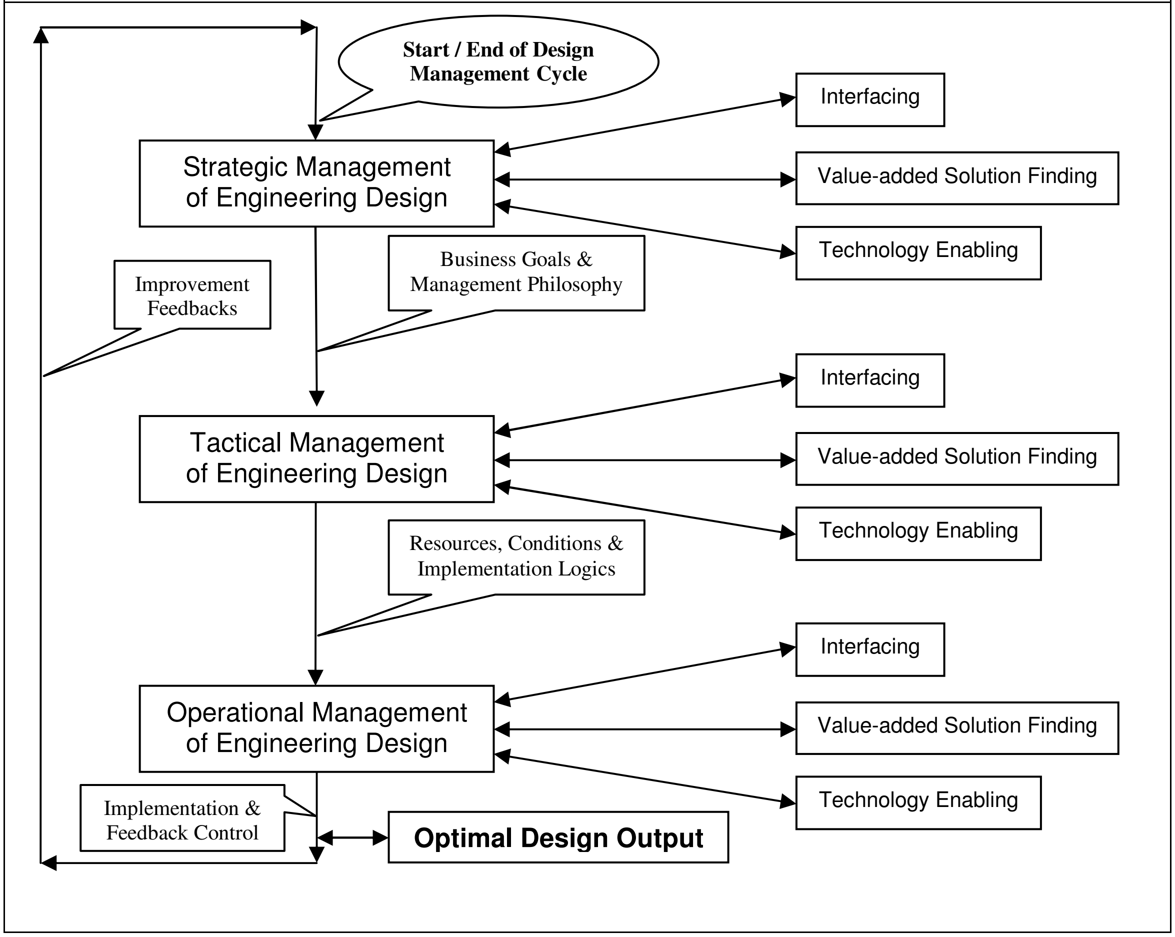
b. Solution Layer and

c. Interface Layer (Conley, 2004).

From the review of existing literatures, the *basic theoretical framework* of the proposed model has been derived as follows. It may be noted here that the Figure 31, described in the subsequent paragraphs, can be treated as a built-up *conceptual lens which has been deployed in the research process,* how this is employed in the present research process has been appositely discussed in pertinent sections (refer Sections 4.1, 4.2, 5.1 & 7.1).

(Figure 3.1 follows in next page)

Figure 3.1: Basic Theoretical Framework



The **Figure 3.1** framework has been proposed by the researcher by integrating his findings from the reviews of existing literatures. Previous researchers have established that design management cycle comprises of *Three Governing Levels –*

i. *Strategic Design Management,*

ii. *Tactical Design Management &*

iii. *Operational Design Management*

(Mozota, 2003a, 2003b, 2009; Sun et al., 2011) and some other researchers have established that *at Each Level*, design expertise can be effectively managed to produce an innovative solution through *Three Layers –*

a. *Enabling Technology Layer,*

b. *Solution Layer and*

c. *Interface Layer* (Conley, 2004).

The researcher has integrated these findings from the existing literatures for proposing this basic theoretical framework of an efficient engineering design management cycle. Further, from data collection and analyses findings, it has been one of the tasks of this research to build up on this Figure 3.1 framework the product-process sides integrated model of piping engineering design management for the oil & gas industry in India.

The Figure 3.1 cycle has the Basic Flow of Activities as follows: the broad business goals for each phase and the piping design management philosophy are created in Strategic Design Management level and flow to Tactical Design Management level, resources required for piping design and management, conducive conditions and implementation logics flow from Tactical Design Management level to Operational Design Management level, the practical implementation consisting of the actual design of the piping system and its management is controlled in the Operational Design Management level and hence this Operational Design Management level also produces necessary improvement feedbacks to the higher governing levels besides yielding the optimal design output, thus completing the piping design management cycle for that phase (Conley, 2004; Howard, Culley, & Dekoninck, 2008).

For systematic & effective innovation integration in each step, the present research uses this knowledge of three layers (Conley, 2004) into each of the three ranges or governing levels of design management and as such, each of the governing levels (1, 2 & 3) are modelled to consist of three core layers – (I) Interfacing, (II) Value-added Solution Finding, and, (III) Technology Enabling. In Interfacing layer, the work problem relevant to that governing level is discussed upon among team members to identify what are the areas of improvement and how can things be further improved. In the Value-added Solution Finding layer, team members brainstorm to find innovative improvements, appraise the emerging innovative ideas in terms of economics & practicability and finally approve the effective innovations. In Technology Enabling layer, the approved innovations are technologically enabled so as to put them into actual practice within the cycle.

The holistic Piping Engineering Design Management Cycle has *Six Phases* namely:

1. Establishing a Need Phase,
2. Analysis of Task Phase,
3. Conceptual Design Phase,
4. Embodiment Design Phase,
5. Detailed Design Phase &
6. Implementation Phase (Howard, Culley, & Dekoninck, 2008).

The management of Piping Engineering Design has *two interfering Sides:*

a. Design Product Engineering Side &

b. Design Process Side (Visser, 1996; Lee et al., 1998; Swink, 2000).

The three governing levels of design management run on both sides (Product as well as Process sides discussed earlier) through each of the six phases of the design management cycle.

Multiple issues are found to be plaguing the design management cycle as seen in all the preceding discussions; the factors plaguing the effective management of engineering design are hereby named issues or challenges; these issues/challenges can be grouped into seven categorical issues and an effective Piping Engineering Design Management Model can be built if these seven issues can be taken care of, as depicted in *Table 3.1: Issues* (can also be called the *constructs); further details on how these constructs have been used* have been described in the later chapters.

Table 3.1: Issues

<table>
<tr><th>Sl. No.</th><th colspan="2">Issues</th></tr>
<tr><td>1</td><td rowspan="3">Design Product Engineering Side</td><td>Objectivity in Design Philosophy (Woudhuysen, 2006) based on Aesthetics, Functionality, Buildability and Economics (Wong, Lam, & Chan, 2009).</td></tr>
<tr><td>2</td><td>Exploitation of the Positive Side of Uncertainty (Neufville, 2004).</td></tr>
<tr><td>3</td><td>Interdiscipline-Dependancy based Design Optimization (Rodriguez, Renaud, Wujek, & Tappeta, 2000) employing a combination of more than one analysis type like Hazard Identification & Operability (HAZOP) Studies, Design & Drawing Reviews in Multiple Stages and Mechanical Audits (Taylor, 2007).</td></tr>
</table>

Sl. No.	Issues	
4	Design Process Side	***Transparent Management** of **Design Knowledge*** (Heerema & Hedel, 1983; Kiwan & Munns, 1996; Zanella & Gubian, 1996; Jokinen, 1997; Kim, Liebich, & Maver, 1997; Martino, Falcidieno, & Habinger, 1998; Herder & Weijnen, 1999; Miles, Gray, Carnduff, Santoyridis, & Faulconbridge, 2000; Sheremetov, Batyrshin, Chi, & Rosas, 2008) including Design Change Orders (Wright, 1997; Ogunlana, Lim, & Saeed, 1998; Wang et al., 2009) maintaining a ***Balance between Top-Down & Bottom-Up*** management methods (Owens, 2000; Dias, Subrahmanian, & Monarch, 2003) ***in each of the Six Phases*** of the design cycle, ***through Sequencing-Controlling-Monitoring*** *(*Visser, 1996; Lee et al., 1998; Rogers & Salas, 1999; Howard et al., 2008).
5		***Effective Communication*** for - Conflict Resolution *by* ***Shared Understanding & treating Assertions as Facts*** (Case & Lu, 1996; Wang, Shen, Xie, Neelamkavil, & Pardasani, 2002; Pena-Mora & Hussein, 1998; Kleinsmann & Valkenburg, 2008), ***Dynamic Bi-Directional Feedback Integration*** (Dearnley & Smith, 1995; Zanella & Gubian, 1996; Busby, 1998; Sheu & Chen, 2007*),* ***Team Integration*** (Reid, Culverhouse, Jagodzinski, Parsons, & Burningham, 2000; Liu, Tang, & Frazer, 2004) & ***Client-Designer Agreements*** (Parent, 1997).

Sl. No.	**Issues**	
6		***Systematic Innovation Integration*** in the Three Governing Levels existing in each of the Six Phases ***through Three Management Layers –*** i. Enabling Technology Layer, ii. Solution Layer & iii. Interface Layer (Conley, 2004), ***by analysing Explicitness, Novelty, Importance & Usability*** of each innovative suggestion/practice (Willaert, Graaf, & Minderhoud, 1998; Swink, 2000; Salter & Gann, 2003; Bertola & Teixeira, 2003; Rieple, 2004; Xu, Houssin, Caillaud, & Gardoni, 2011).
7		Rework Minimization (Ahire & Dreyfus, 2000; Chua & Tyagi, 2001) by ***Identification & Elimination of Non-value adding activities*** (Chua & Tyagi, 2001).

Researches in many countries, none of which has focused on India, so far have identified that *an Effective Model for integrated Design Management can be built if these 3 issues on product side & 4 issues on process side are taken care of*. However, previous research has proven that engineering design thinking & corresponding *design activities in different industries in differing situations have crucial differences* (Visser, 2009) as exemplified in earlier Chapters and therefore, the earlier discussed design management studies, undertaken in other industries, are uncertain in terms of their applicability to the oil & gas industries and no research has been done on their applicability to the oil & gas industries. Furthur, previous research has proven that *design management roles & practices vary from country to country* (Sun et al., 2011) as discussed earlier. From the existing literature review, it has been found that no research has focused on whether there are any issues plaguing the management of engineering design in India. The existing studies have identified issues plaguing engineering design management worldwide in other industries & outside India. Further, design management practices vary from industry to industry and from country to country. Therefore, the *applicability of those identified issues to the Indian oil & gas context is uncertain*. No study has focused on their applicability to either the oil & gas industry or on their applicability to India. Moreover, previous researchers have stressed the growing & indispensable need for a *comprehensive design management model* and in India no research has focussed on engineering design management.

From the comprehensive reviews of existing literatures, it is found that there have been some researches in this broader field of *Multidisciplinary Engineering Design Management for industries other than Oil & Gas*. There have also been some researches in the *Management of specifically Piping Engineering Design in industries other than Oil & Gas* as discussed earlier. However, engineering design thinking & corresponding *design activities in different industries in differing situations have crucial differences* (Visser, 2009) as discussed with examples in earlier paragraphs.

It has been found that all *researches, except one (Sheremetov, Batyrshin, Chi, & Rosas, 2008), focused on the product side of piping in industries other than oil & gas; however, all of these have focused only from a purely engineering point of view, leaving a colossal dearth of focus on the management aspects in the product as well as the process sides of design management*. The only one research found on *Oil & Gas Piping Engineering Design Management* has been done too purely from an engineering point of view outside India (Sheremetov, Batyrshin, Chi, & Rosas, 2008); Sheremetov et al.'s (2008) research has been focused on only one modelling aspect - integrating piping analysis like stresses and flexibility with piping design like layouts, etc. of oil & gas piping engineering design management but this research's engineering recommendations too may not be applicable to India since *design management practices vary from country to country* (Sun, Williams, & Evans, 2011). The only one research found on *Oil & Gas Piping Engineering Design Management* has been done too purely from an engineering point of view (Sheremetov, Batyrshin, Chi, & Rosas, 2008) and *may or may not be applicable in the Indian context because design management practices vary from country to country and no study has focussed on engineering design management in India.*

The existing studies did *neither focus on the management aspects present in both the product sides and the process sides nor into any integrated model for the complete cycle that caters to the management issues of the product as well as the process sides*. However, previous studies have established that *design management roles, practices & activities significantly vary from industry to industry (Visser, 2009) and from country to country* (Sun, Williams, & Evans, 2011) as exemplified in the earlier paragraphs. Further, the previous studies *neither throw any light on the oil & gas industry nor on the design management issues*. Therefore the identified seven issues, that have all emerged from research in other industries in other countries, may or may not be applicable to India. From the existing literature review, it has been found that no research has focused on whether there are any issues plaguing the management of engineering design in India. The existing studies have identified issues plaguing engineering design management worldwide in other industries & outside India. Moreover, design management practices vary from industry to industry and from country to country. Therefore, the applicability of those identified issues to the Indian oil & gas context is uncertain. No study has focussed on their applicability to either the oil & gas industry or on their applicability to India. Moreover, previous researchers have stressed the growing & indispensable need for a comprehensive design management model and in India no research has focussed on engineering design management.

It may be noted here that this particular Chapter reviews & discusses the relevant existing literature. All the findings from the existing literature review led to the development of the conceptual lens and the constructs, as chronicled in the next Chapter 4: Research Design.

The findings from the preceding discussions led to the research questions of how piping engineering design is being managed in the Indian context, with/without any existing model, what are the issues there and how those can be catered to through a model of piping engineering design management.

From all the preceding detailed discourses, the business management problem, research gaps, research problems, research questions & research objectives are summed up as follows.

3.3 Business Problem

The business management problem is:

An ***integrated model for managing engineering design*** is indispensably needed to aid design engineers/managers in their management decisions and to sustain the ***competitive advantage of the company***.

To solve this business problem, address the research gaps, answer the research questions and fulfill the research objectives, the existing practices of piping engineering design management that are being used in the piping engineering design department of India's largest oil & gas company have been studied, issues identified, compared with other researchers' finding, each research step has been deeply thought upon, profoundly analyzed, rigorously verified and an integrated model of piping engineering design management has been proposed as discussed in the following Chapters.

3.4 Research Gaps

The emerged research gaps are:

Extensive literature review yielded no references of any *design approaches & models for oil & gas piping engineering design management in India.* There has been no research to know how design is being managed in India.

From the existing literature review, it has been found that no research has focused on whether there are any issues plaguing the management of engineering design in India. The existing studies have identified issues plaguing engineering design management worldwide in other industries & outside India. Moreover, design management practices vary crucially from industry to industry and from country to country. Therefore, the *applicability of those identified issues to the Indian oil & gas context is uncertain*. No study has focussed on their applicability to either the oil & gas industry or on their applicability to India. Moreover, previous researchers have stressed the growing & indispensable need for an *integrated design management model* and in India no research has focussed on engineering design management.

Previous studies have established that an integrated management model for managing engineering design is indispensably needed. The previous studies have their respective limitations. Some researchers have focused only on the Product Side of Engineering Design Management and have so far found out three issues challenging the efficient management on engineering design on the Product Side. Whereas some other researchers have focused only on the Process Side of Engineering Design Management and have so far found out four issues challenging the efficient management on engineering design on the Process Side. Existing literature review has evidenced that engineering design management can be effectively managed if the identified issues are catered to. Previous studies for specifically piping engineering design management have focused only from a pure engineering point of view, ensuing a colossal dearth of focus on the management aspects in the product as well as the process sides of design management; the existing studies did neither focus on the piping enginering design management aspects present in both the product sides and the process sides nor into any integrated model for the complete cycle that caters to the management issues of the product as well as the process sides. Further, it has been found that no research has focused on whether there are any issues plaguing the management of engineering design in India. An extensive literature review covering over three hundred relevant available literatures yielded no references of any design approaches & models for oil & gas piping engineering design management in India. The previous studies neither throw any light on the design management in the global oil & gas industry nor on the design management issues of any industry in India. There has been no research to know how design is being managed in India. The existing studies have identified issues plaguing engineering design management worldwide in other industries & outside India. However, previous studies have established that design management roles, practices and activities significantly & crucially vary from industry to industry and from country to country. Therefore, the applicability of those identified issues to the Indian oil & gas context is uncertain. No study has focussed on their applicability to either the oil & gas industry or on their applicability to India. Moreover, previous researchers have stressed the growing & indispensable need for an integrated design management model and in India no research has focussed on engineering design management. The identified research gaps have not been addressed by any of the previous studies. This present research tries to answer these questions and thus address these dodged research gaps in a bid to improve engineering design management in India.

3.5 Research Problems

The two research problems are:

The Existing Practices/Models of Piping Engineering Design Management that are being used in Oil & Gas Industry in India are unknown, although are indispensably needed to be known in order to sustain the competitive advantage of the company.

The Areas of Improvements or Issues, that are needed to be identified in order to develop a Model of Piping Engineering Design Management, are also unknown.

3.6 Research Questions

The two research questions are:

HOW Piping Engineering Design is being managed in oil & gas industry in India?

WHAT are the areas of improvements in the existing practices/models and *HOW those areas can be catered to through a Model* of Piping Engineering Design Management?

3.7 Research Objectives

The two research objectives are:

To Study the Existing Practices/Models of Piping Engineering Design Management that are being used in oil & gas industry in India.

To Identify the areas of improvements in order to develop a Model of Piping Engineering Design Management.

In this Chapter the connate conceptual framework has been discussed. The proceeding Chapter describes the research design that is the basic plan for doing this research study.