Holonic (HM), Fractal (FM) and Bionic Manufacturing (BM): A Brief Literature Review and Few Propositions

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Abstract

In this paper we start with a brief literature review on HM, FM and BM. Then we relate these among themselves to argue that FM = HM + BM. We map these advanced manufacturing technologies to the strategy of the organization. Later we give several interesting hypotheses and conjectures. Finally we draw a table that relates different types of flexibilities of HM, FM and BM.

Keywords
Holonic, Bionic and Fractal Manufacturing, Strategy of Organizations and PWP (Plant With In A Plant)

1. Introduction and Literature Review

For advanced information systems in Supply Chain and Organizations refer to Xu (2011). Agent is a software entity that can autonomously with its environment. Management practice has gone up to level (as enterprise social media & social media) where many routine jobs can be automated. And typically in the context of AMT as above, functional agents (such as production, marketing, HR, finance) that have routine jobs that can be automated. And agents (functional agents) can use predictive analytics. As Lawrence and Lorsh have noted, organizations need to do differentiation (along functional lines) and must do integration (and this in the context of AMTs means there has to be an integrating agent that is also known as goal determination agent). And integration still is an art that has to be performed by chief executive, the analytics is diagnostic (as uncertainty is high, the goal determination is increasingly difficult). Typically in Holonic manufacturing integrating agent is highly required, and in Fractal manufacturing this integrating module is easier (as it uses the concept of PWP & in each PWP there is high centralization). In FM resources are redeployed as market conditions change. And this has following implications.

Extreme Programming is used for software development for Holonic/Fractal manufacturing (that are exposed to higher levels of uncertainty (here priority of objectives change very often) as it assumes the strategy of analyser), that have reconfigurable properties; and this is required as the system tends to mimic goal determination agent. Here there will be loose coupling (and here use of service oriented architecture is recommended). In case uncertainly is a bit less and one may go for SCRUM programming.

Management control systems tends to be increasingly diagnostic for those elements that are-automated in the form of AGENTS; and lesser portions of operations/strategy making is INTERACTIVE.

Bionic manufacturing tends to mimic the human system (that is composed of nerves and brain); here nerves denotes centralized decision making. Here software development process is FDD (feature driven development); and here there is tight coupling. In BM goal determination is much easier. As all manufacturing resources are reconfigurable, BM, HM and FM can co-exist in a factory. However in general learning curve may not be there as there is frequent reconfiguration as market conditions change. A clarification: in Holonic manufacturing there is goal determination/integrating agent; and in FM there is PWP and goal determination is within a plant and in

HM and FM integration is difficult as market conditions change frequently. (See Wiki on advanced, holonic, fractal and bionic manufacturing).

For a good treatise on strategy refer to Miles and Snow (1978). The three chief strategies are cost leaders (CL), differentiators (DIFF) and analysers. Each of them have distinct organization structure and systems (see Chatterjee 2011). For a useful taxonomy of manufacturing strategies refer to Miller and Roth (1994). Cost leaders use mass production and differentiators use job shop/FMS and Analysers have PWP (plant within a plant concept) and use mass production for low cost items (sold in large numbers) and deploy job shop/FMS for relatively high end products. In terms of systems we can say that differentiators face higher levels of uncertainty and have 'interactive' control systems; whereas CL have 'diagnostic' control systems where a few critical variables are monitored to ensure performance.

Most of the concepts related to HM, BM and FM are taken from four books of Sharma (2019) published with LAP-LAMBERT. Below we relate holonic, bionic and fractal manufacturing to strategy, structure and systems of organizations.

2. Theoretical Framework:

2.1 Holonic, Fractal and Bionic Manufacturing: Few Propositions

(H1): In cost leader (CL) firms, decisions are made at the top and the organization at the lower levels obey it; and supply information to top. Hence, Bionic mfg systems are ideally suited to make mass production system more agile.

(H2): Holonic manufacturing is a bottom up system; and is ideally suited to make FMS (conventional flexible mfg system) more agile. This is primarily suited for organizations with differentiation/innovation strategies.

(H3): Fractal mfg is Holonic + Bionic Mfg. It is basically based on concept of PWP. For firms with mass production on uses Bionic Mfg and for areas where there is differentiated product offering one can use Holonic manufacturing. It allows customer to schedule his jobs on the production floor; and system (Holonic mfg) allows customer to see when his job can be ready; if not satisfied, customer can pay more to get some VIP treatment. This is primarily suited for organizations with analyser strategy.

2.2 Few Propositions on System Software for Holonic, Fractal and Bionic Manufacturing

(H4): Decoupling in Bionic Mfg is low (in the system software development).

(H5): Decoupling in Fractal Mfg is high (in the system software development).

(H6): Decoupling in Holonic Mfg is very high (in the system software development).

(H7): Bionic mfg has is suitable for low uncertainty levels; Fractal and Holonic mfg are suitable for respectively high and very high levels of uncertainty.

2.3 Holonic, Fractal and Holonic MFG: A Conceptual Framework

In PWP (plant within a plant) each PWP has bionic mfg; and this has top-down structure. A cell is autonomous. As the product in a plant is phased out, the resources of this cell is allotted to other products/cells. So they are co-operating with each other. Those products cannot afford a separate cell, then they are assigned to HOLONIC MFG; so we can see that HOLONIC + BIONIC = FRACTAL.

(H8): We can have combination system (Bionic, Fractal and Holonic Mfg) in the same factory.

The above is useful as it helps us to have a clear understanding of the new Intelligent and Agile mfg systems that are evolving since 1970.

2.4 Flexible Organizations and Holonic, Fractal, Bionic, CIMS and Digital Manufacturing

(H9): Holonic and Fractal Mfg will be associated with associated with flexible organization structure (direction of causality is not known at the moment).

(H10): Digital, Bionic and Computer Integrated Mfg systems will not be associated with flexible organization structure (as these mfg technologies are predominantly centralized).

2.5 Holonic Manufacturing and Strategy of the Organization

In the context of FMS (Flexible mfg Systems) FMM (flexible mfg module) is the smallest unit; and FMM can be combined to get FMC (flexible mfg cell); FMG (flexible mfg group) and FML (flexible mfg line).

Similarly in Holonic mfg, smallest resource unit (holon: in the context of FMS it is FMM) can be combined to get different mfg configurations. As the market demand is highly volatile (such that even cost leadership products have volatile demand and need to be reconfigured; and there are short product life cycles make many products extinct) we can reconfigure the Holons to get new product/process layouts (for plant within a plant).

In light of above, we have the following.

(H11): In cost leadership strategy, using Holonic Mfg will not use its potential to the full.

(H12): For differentiation strategy, there is good fit between strategy and Holonic mfg.

(H13): In Analyser strategy, there is ideal fit between strategy and Fractal mfg.

Comment: As in Holonic Mfg reconfiguration is a major problem, solution to DPLP (Dynamic Plant Layout Problem) in real time is a big help.

2.6 Holonic, Fractal and Bionic Manufacturing

(S1): Bionic mfg is a top down approach and is suitable for Cost Leaders (CL).

(S2): Fractal mfg goes for cell formation (uses PWP: Plant Within a Plant) and goes for decentralization; and hence do not need a Goal Determination Agent. So we say in crude form: Fractal mfg has many Bionic modules.

(S3): The Holonic mfg uses a bottom up approach, requires interaction between top management and the knowledge workers operating at lower levels; and needs a Goal Determination Agent.

(S4): If Fractal mfg can have PWP for every product (it is an expensive approach: as a resource/machine can be added to every product and its associated cell/PWP) and go the Fractal way. Then for a number of low volume products one goes for Holonic mfg.

2.7 Digital Manufacturing and Holonic, Fractal and Bionic Manufacturing

In general, if we have less complexity (either due to streamlined flow or decentralization as PWP (plant within a plant)) then it is easier to implement Digital Manufacturing. Hence we state the following.

Conjecture 1: Digital manufacturing is easiest in Bionic manufacturing, it would be easier in Fractal Manufacturing and it will be moderately difficult in Holonic manufacturing.

2.8 AMTs (Fractal and Holonic Manufacturing): Few Conjectures

Lot sizing becomes irrelevant in the context of holonic/fractal mfg). Carbon footprint will be high in holonic/fractal/bionic mfg.

Conjecture 2: These technologies are much more expensive as they have very high overheads; and the reconfiguration cost is kept low by the use of SoA (service oriented architecture). If there is a wide variation in profitability of different jobs, then accepting/scheduling jobs in terms of contribution/dollar value rule for scheduling jobs would be a good idea (in holonic, fractal mfg where profit is the prime objective). It is reported in literature that customers can schedule their jobs online by paying extra; and this will be practiced in these AMTs. This will be able to boost the bottom line. With these AMTs, produce to stock concept goes away (customer will have to pay hefty advance); and this will be geared to cater to the rich/elite class.

Conjecture 3: Costing methods used in these technologies could be as follows: Variable Costing (To decide if job is to be accepted/ not accepted; It will be a Short Term phenomenon: it will be used very sparingly). The other costing method used will be allocation of overheads in terms of processing time by taking into account capacity utilization; and it will be most frequently used. Not used costing method will be standard costing as these AMTs will have a custom made product. Also not used will be the methods that are used for valuation of inventory (as here we will not be producing to stock).

2.9 Can Holonic/ Fractal/ Bionic Manufacturing Replace MRP-2 and JIT? Few Observations

Conjecture 4: Given the large number of population that belongs to 'have not' category, conventional mfg JIT & MRP2 will continue to be used. This is from economic point of view.

More over as resources are frequently re deployed, the Bionic Mfg (that is top down) will not be able to have the Learning Curve Effect that conventional JIT is able to have.

Conjecture 5: Holonic/ Fractal/ Bionic Manufacturing as yet will not be able to replace MRP-2, as these AMTs (Holonic/ Fractal/ Bionic Manufacturing) are not geared for complex product structures such as Naval Ships and Aero planes. Also these AMTs are ill prepared to handle the layout by fixed position that is used frequently in manufacturing of Naval Ships and Aero Planes.

2.10 Evaluating Holonic and Fractal Mfg (HM/FM)

Evaluating Holonic Mfg would be similar to evaluating a shop where MRP is being used. Here lot sizes are few, and product variety is very high; and hence the criteria would be: set up cost (generally low in HM), Inventory carrying cost, machine utilization, shortages, machine downtime, capacity utilization and delays (tardiness of jobs).

Whereas, in FM, criteria are different for each of the fractals, that are dedicated to a specific product/segment.

In the context where a product has sufficiently high volumes and it can afford a separate plant (known as PWP: done in fractal mfg) then such reconfigurable mfg systems, have higher tolerance to change; whereas, in HM integration levels are high, and as a consequence here there is lower tolerance to change (relatively).

2.11 Manufacturing Flexibility in Additive, Holonic, Fractal and Bionic Mfg

Type of Flexibility	**Additive Mfg**	**Holonic Mfg**	**Fractal Mfg**	**Bionic Mfg**
Volume F	L	L	H	H
Machine F	H	H	H	H
Routing F	NA	H	NA/ Uses PWP	L
Material Handling F	NA	H (AGVs)	H (AGVs)	H (AGVs)
Product F	H	H	H/L	L but can be high

3. Conclusion

In this paper we gave a state of art literature review on bionic, holonic and fractal manufacturing. We related these to each other so that we get a better understanding of these manufacturing systems. We related these concepts to the strategy of the organizations. Several interesting propositions, conjectures and statements are given. This is a useful contribution we make in this paper. Most of the novel ideas presented in this paper are taken from four books of working papers by Sharma (2019-2021).

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Biographies

Prof. RRK Sharma: He is B.E. (mechanical engineering) from VNIT Nagpur India, and PhD in management from I.I.M., Ahmedabad, INDIA. He has nearly three years of experience in automotive companies in India (Tata Motors and TVS-Suzuki). He has 32 years of teaching and research experience at the Department of Industrial and Management Engineering, I.I.T., Kanpur, 208016 INDIA. To date he has written 1192 papers (peer-reviewed (389) /under review (22) / working papers 781 (not referred)). He has developed over ten software products. To date, he has guided 64 M TECH and 21 Ph D theses at I.I.T. Kanpur. He has been Sanjay Mittal Chair Professor at IIT KANPUR (15.09.2015 to 14.09.2018) and is currently a H.A.G. scale professor at I.I.T. Kanpur. In 2015, he received "Membership Award" given by IABE USA (International Academy of Business and Economics). In 2016 he received the "Distinguished Educator Award" from IEOM (Industrial Engineering and Operations Management) Society, U.S.A. In 2021, he received IEOM Distinguished Service Award. In 2019 and 2020, he was invited by the Ministry of Human Resources Department, India, to participate in the NIRF rankings survey for management schools in India. In 2019, he was invited to participate in the Q.S. ranking exercise for ranking management schools in South Asia.

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