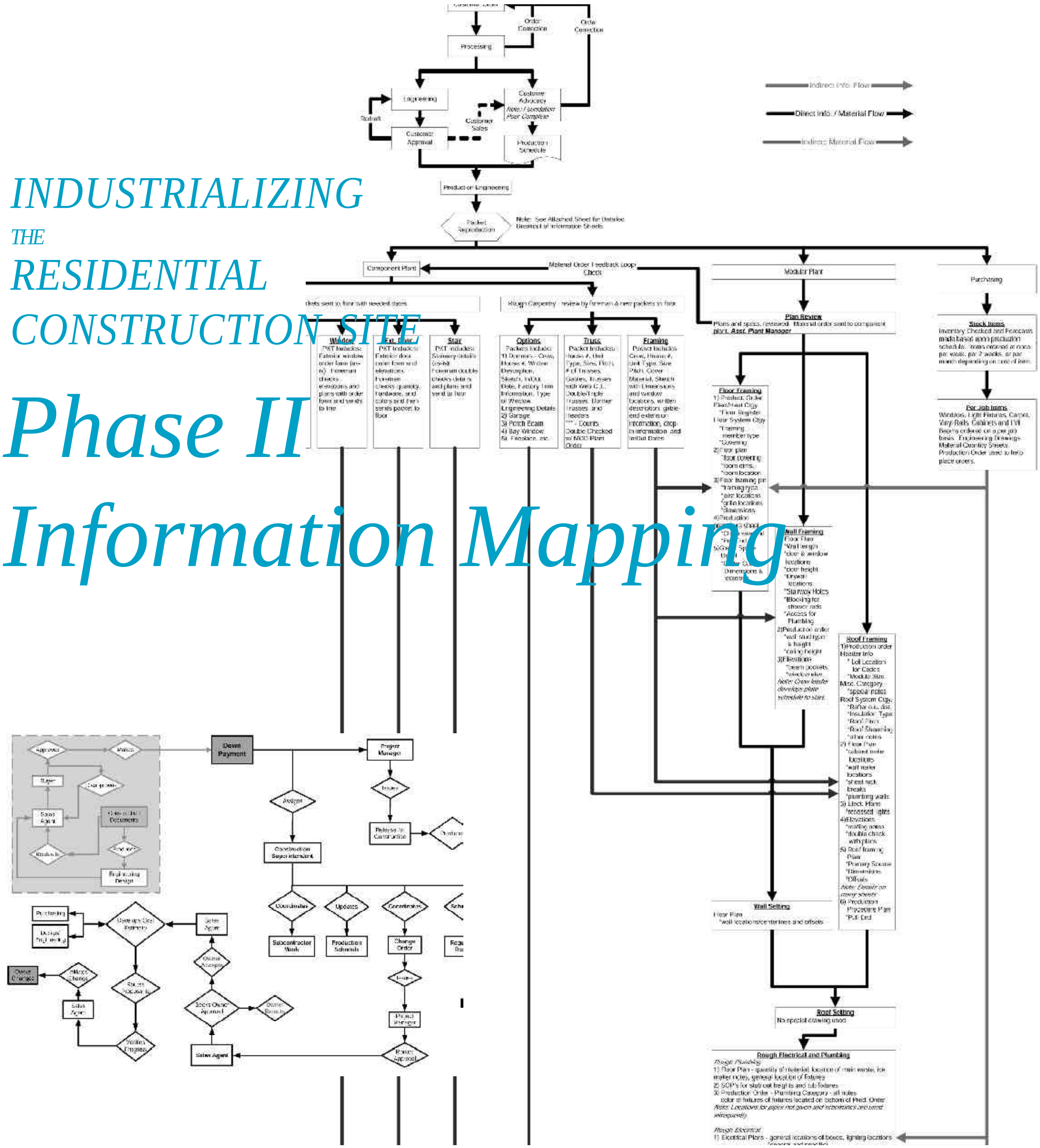
INDUSTRIALIZING
THE
RESIDENTIAL CONSTRUCTION SITE

Phase II
Information Mapping



Industrializing the Residential Construction Site
Phase Two: Information Integration

Prepared for the Department of Housing and Urban Development, Office of Policy Development and Research, Washington, DC 20410

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Disclaimer

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Foreword

Home ownership has reached record highs over the last few years. As a consequence, home production has also benefited from the tremendous need for new homes in America's cities and towns. Despite these demands, the home building industry still lags behind other industries in technological innovation and adoption—that is, in providing new homes more quickly and more efficiently while still keeping homes affordable and of a high quality. New techniques, materials, tools, and organizational methods are often limited to specific parts of the country among specific builders because of the obstacles in spreading those ideas nationally. There is much that can be done, and there is much that all the participants in the home building industry would like to see done.

Two years ago, HUD began an ongoing research project to address this crisis. While, much of HUD's technological research work looks at the materials from which homes are built, we realized how important the processes for construction are for homes and home builders: or, *how* houses are built. Ways to automate home construction processes, to improve construction work flows, and to practically coordinate construction sites—known as *Industrializing the Residential Construction Site*—became a new research focus. In the first year's effort, *Phase I*, researchers laid out five areas that best contained the possibility of transforming the construction site: production integration, operations integration, performance integration, information integration, and physical integration.

Of these five, HUD chose to first explore "information integration" in order to see how information exchanges, relationships, and mechanisms shaped construction operations. As the common denominator on all construction sites, information is a critical beginning for understanding integration, and one that HUD believes is central to this ongoing research. This document, *Phase II: Information Mapping*, is the product of that research, and is one that HUD is proud to publish. It includes an amazing record and analysis of the information flows and breaks on construction sites, as well as recommendations for overcoming these breaks.

Such a comprehensive and integrated approach to information, the basic building block of any industry's work, will have dramatic consequences for all of housing production. This first in-depth exploration of those processes opens an entirely new approach to helping home builders and building trades understand how their work is structured, and how it can be improved. Ultimately, these improvements will also benefit America's home owners and buyers. Research initiatives and results like those in this series directly support the home building industry's future production capacity and the quality and cost of American homes for years to come. We invite you to read this report and its precursor. We also invite you to look out for more advanced research from HUD in this field.

Lawrence L. Thompson
General Deputy Assistant Secretary for Policy Development and Research

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Chapter One: Introduction to Phase Two of Industrializing the Residential Construction Site

1

Software tools for managing information abound today. Flat file, relational, and object-oriented database tools are available in scales appropriate for managing small, medium and very large sets of information. As Enterprise Resource Planning (ERP) tools, large, sophisticated databases have been the foundation for the rebirth of economic sectors ranging from agriculture to manufacturing. Manufacturing and heavy industries producing raw materials have a long history of intricately studying their processes—knowing each tenth of a penny saved on a production unit could mean millions of dollars in production cost savings.

The implementation of these software tools in the residential construction industry, however, has been slow, partly due to the varying scales and production rates of homebuilders, but perhaps mostly due to diverse business models and practices used by the homebuilding industry. This second phase of "Industrializing the Residential Construction Site" focuses on the flow, filtering, and timely availability of information at three scales of homebuilders.

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INFORMATION MODELS

At a recent national symposium on information systems for residential construction, it became quickly apparent that the two primary groups meeting—software developers and builders—had starkly opposing expectations of which group was going to adapt or revise its methodology for the other. The overall tone of the software developers' discussions could be distilled to, "We have this product. It can do these things. If you change your business practices, our product would solve your problems." The builders' tone might be summarized as, "This is our business practice. It reflects the complexity of our industry. Why can't your tools do the same?"

This mismatch indicates the need for mediation. Software developers need an information model to make tools appropriate to the residential construction industry, and the industry needs a translation of its business practices into the language of information models to successfully implement these tools across office and field operations.

Information modeling is a procedure for representing the information policies, practices, and relationships in use by a business. As an explicit record of intuitive or implicit characteristics that trigger actions and decisions, the information model is the rationalization (i.e., the identification, categorization, and ordering) of the many rule sets in use by employees in daily business. Rationalization is a difficult, time-consuming process that has not been undertaken by the residential construction industry and thus is the major obstacle to successful implementation of information technology.

Rationalizing the wealth of information on residential construction sites into an information model would involve tracing out five logical components: *object types, relationships, operations, data elements,* and *regulations*:[1]

· *Object types* are people, places, things, documents, organizations, agreements or policies playing a specific role in a business organization.
· *Relationships* are named associations between two or more object types which are the result of interaction between object types.
· *Operations* are actions changing the state of the business system being modeled, such as transactions and events.
· *Data elements* are facts describing the object types or relationships (phone number, name, etc.).
· *Regulations* are rules governing the content, structure, integrity, and operational activity of the model, expressing high-level policy constraints.[2]

The following pages describe how these five logical components work themselves into a variety of construction sites and into a variety of information processes. These will serve as the first steps to bridging the gaps between construction means and information needs.

1 Flavin, M. 1981. *Fundamental Concepts of Information Modeling*. Yourdon Press, New York, p. 11.
2 Flavin 1981, p. 12

Chapter Two: Selection of Builders for Case Study in Information Management

2

In *Industrializing the Residential Construction Site*, Chapter Four, "Potential Technologies for Industrialization in the Current Home Building Industry,"[1] the homebuilding industry was categorized into

- small-volume residential builders—building fewer than 20 homes per year;
- medium-volume builders—building up to several hundred homes per year in regional markets;
- high-volume builders—building more than 1000 homes per year, utilizing on-site construction methods, with a regional or national presence; and
- production builders—using off-site fabrication including modular, manufactured (HUD code), and factory-based panelizers, undertaking the majority of their work in a factory environment, and delivering consolidated materials to sites in fewer than 10 deliveries from a single factory.

With these categories in mind, this project studies the information flow, production processes, and information filtering employed by the medium-volume, high-volume, and production builders because they are likely to have in place explicit business practices supporting the construction of a general information model for residential construction.

This project studies the information flow, production processes, and information filtering employed by the homebuildering industry.

Specifically, builders were chosen based on

- annual volume of residential construction,
- willingness to cooperate and allow study of proprietary business practices and methods,
- accessibility to the field researchers, and
- state of rule-based processes in place.

1 O'Brien, M., R. Wakefield, and Y. Beliveau, 2000. *Industrializing the Residential Construction Site*. U.S. Department of Housing and Urban Development, Office of Policy Development and Research, Washington, D.C.

3

Chapter Three: Data Collection Methods for the Selected Case Study Builders

To study the information flow, information filtering activities, and milestone events and to identify personnel positions that are key information nodes, data collection methods were varied to adapt to the differences between corporate policy, focused on process, and field practices, focused on the process.

Data on overall *corporate policies* was collected in direct interviews with officers of the corporation. Information gathered in these interviews formed the road map for subsequent interviews with key managers of each subprocess. Wherever possible, specific examples of forms, drawings, and schedules were obtained (See Appendix A).

Data collection on *field practices* affecting production, scheduling, and incentives was accomplished primarily through observation and informal conversation with the site superintendent. These methods yielded greater quantities of more accurate data but were still limited by the degree to which the superintendent was able to spend time with the researcher.

Because of the nature of the subject and the finite number of observations, this data collection and its subsequent analysis are meant to be representative of construction practices rather than statistically accurate documentation of those practices for the whole industry. As such, they are a first attempt at documenting information flows for residential construction.

Data collection methods were varied to adapt to the differences between corporate policy focus on process and field practices focused on process.

Observations and interview questions were focused on collecting data to record:

- overall production and monitoring processes at the corporate level,
- approval and progress milestones,
- trigger events in the process,
- the media employed in generating the information product from each stage of the process,
- the information products received at each stage of the process,
- the specific data elements used by each stage of the process,
- instances of information filtering (interpretation, representation, used by managers,
- instances of disconnects in timing, accuracy, or completeness of information,
- instances of disconnects between field practices and scheduling and corporate policy,

- instances of redundancies in information, and
- corporate incentive programs affecting information flow and pro duction.

Interviews and observations were conducted between September 2000 and January 2001. Typically, a corporate officer in each firm was contacted by telephone and asked make an appointment for an introductory visit wherein a researcher and principal investigator would describe the project goals and request interview time with key managers of the production process and permission to collect examples of forms, drawings, and schedules used in the production process.

The on-site observation visit conducted by a researcher lasted two to four days. During this period, the researcher walked through the production process from purchase through order processing and into the field to observe field practices for scheduling, subcontract coordination, changes, quality assurance, and closing while recording the data listed above.

Following the on-site observation, the researcher assembled the data to map the information form and flow to the production process. Information inputs, filtration, and outputs were mapped to the overall process. Any gaps in the data revealed by the mapping activity were cataloged and addressed during a follow-up site visit. The production process, information used at each stage, information disconnects, trigger events, and milestones were mapped together to develop an overall diagram of the interaction between field and office processes. For each builder, more detailed data on one specific aspect of the process (e.g., owner-initiated change or roof framing) was collected and separately mapped. A narrative describing the data collection, production process events, information used, citations of information filtering, disconnects, and milestones was written and attached to the process map. All examples of process forms were numbered, keyed to an index map, and filed for future reference.

A listing of these documents can be found in Appendix A.

Chapter Four: An Analysis of Field Data and Observed Potential Information Disconnects 4

This chapter begins with a discussion of the general methods of analysis. The first stage of the analysis involved data structuring and integration using a process map. The second stage studied information filtering and document use. The final stage identified potential information disconnects across the construction system. Sections 4.2 through 4.6 discuss the analysis and findings for each builder in turn.

DATA STRUCTURING AND ANALYSIS

Data was classified into three areas: process data relating to field construction and management of the construction system; documents that support field construction; and management of the system, and supplier and component relationships.

A process map was developed for each builder to structure the data and establish relationships among management, field construction, documents, and suppliers. Once each process map was developed, it was used to identify and characterize information disconnects in the construction system. These maps:

- reveal information paths (both actual and predicted) and the relationships among documents, information, and field construction
- permit analysis of filtering of information throughout the construction system, and
- provide a point of comparison across builder groups.

BUILDER ONE

Figure 4.1 shows the process map for the Builder One construction system. The process map identifies information and material flows within the system. The main focus of the map is on materials and information necessary to build the structure.

The Builder One construction system uses a component-based assembly approach. Components are prefabricated in a separate component plant and then assembled in another plant to form the house module. This approach enables concurrent construction of components in the component plant so that parts can be delivered to the assembly plant as required. The module assembly plant also uses concurrent construction of the mod-

The process maps give the reader an opportunity to develop an understanding of information paths, both actual and predicted, and permits analysis of information filtering.

Figure 4.1.foldout Process map for Builder One
Click here for link to map

ule base—the floor, wall, and roof systems. These systems are then combined before other component assemblies are added in the construction process.

HOMES
ROOF COMPONENTS ORDER
FOR 5 ; 7 ; 9 ; 12/12 DOUBLE FOLDING ROOF SYSTEMS

PARTS ORDERED BY:____________________

FACTORY NO.____________ BUILDER:______________________ MS#________

MODEL NAME:________________ UNIT SIZE____________________

DATE ORDERED:____________ DATE NEEDED:______________ TIME NEEDED:______

ATTENTION RAFTER FABRICATOR: REFER TO PRODUCTION RAFTER DETAILS

QUANITY	DESCRIPTION OF COMPONENT
	EA.__/12 PITCH DBL. FOLD RAFTERS:_SGL:_DBL:_TPL: FOR __12 WIDE OR __14 WIDE
	EA.__/12 PITCH DBL. FOLD RAFTERS:_SGL:_DBL:_TPL: FOR __12 WIDE OR __14 WIDE
	EA.__/12 GABLE RAFTERS / EA. ___/12 GABLE RAFTERS
	EA.__/12 PITCH RIDGE DROP-INS----MEMBERS @ ______" ON CENTER
	EA. _/12 PITCH RIDGE DROP-INS----MEMBERS @ ______" ON CENTER
	EA. _/12 PITCH : ____DEPTH OVERHANGS (7/12-16"@24"OC OR 12/12-8"@19.2"OC ONLY)
	EA. _/12 PITCH : ____DEPTH OVERHANGS (7/12-16"@24"OC OR 12/12-8"@19.2"OC ONLY)
	EA. _/12 PITCH LONG GABLE EXT. / EA. _/12 PITCH LONG GABLE EXT.
	EA._/12 PITCH SHORT GABLE EXT. / EA. _/12 PITCH SHORT GABLE EXT.
	EA. __/12 PITCH ; __12 WIDE ; ___14 WIDE GABLE FOLD-IN (FOR DBL. FOLDING ROOF) (COVER WITH ; __ENERGY BRACE ; __3/8" PLYWD. ; __1/2"PLYWD. ; __5/8" SR)
	EA. __/12 PITCH ; __12 WIDE ; ___14 WIDE GABLE FOLD-IN (FOR DBL. FOLDING ROOF) (COVER WITH ; __ENERGY BRACE ; __3/8" PLYWD. ; __1/2"PLYWD. ; __5/8" SR)

Figure 4.2. Component order to roof component workstation.

Figure 4.1 shows direct as well as indirect material and information flows. Indirect material flows are those not formally controlled by the production/assembly process; for example, components are constructed then delivered to the staging area until they are ready to be used in the assembly process. Indirect information flows are those not directly involved in the production process; for example, oral order confirmations, instructions, and checks.

In the Builder One system, the information "generation" for the building process occurs at the end of the production-engineering phase. At this stage, information packets are prepared for all parts of the construction process: the component plant, modular plant, and the purchasing division. The contents of a typical packet are listed in Appendix A. The information handling process is different for the component operation and the assembly operation. In the component operation, the plant manager receives information packets, filters them, and forwards only information necessary for particular component construction to the appropriate component plant workstations. Figures 4.2 and 4.3 show the typical information going to a component workstation. Further filtering of this information occurs at individual workstations. Figure 4.4 gives a typical example of filtering at the roofing workstation, while Figure 4.5 shows a typical roof framing plan.

In the module assembly plant, a component set of documents accompa-

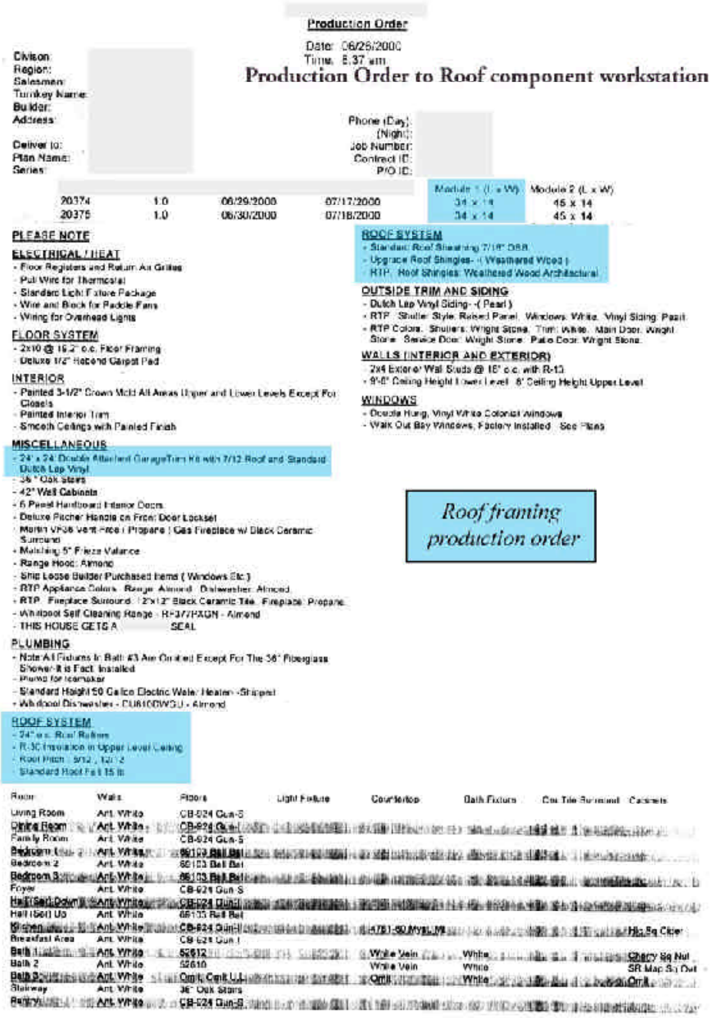


Figure 4.3. Production order to roof component workstation.

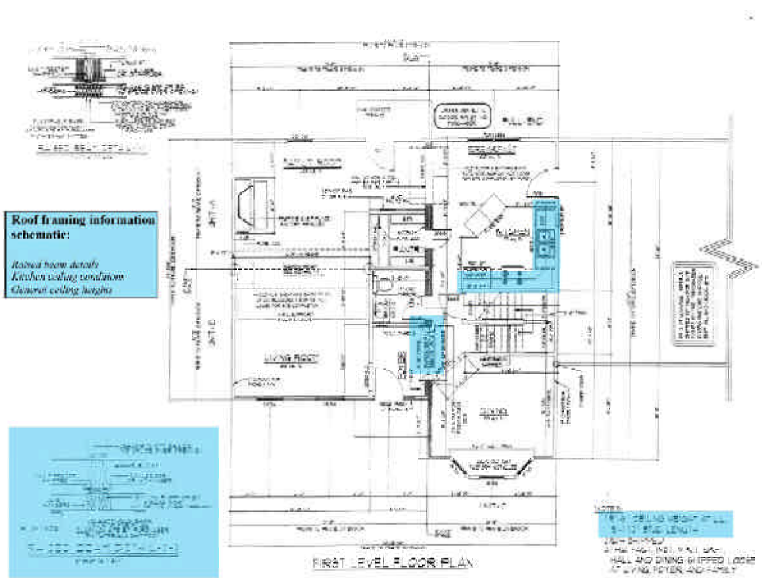


Figure 4.4. Typical example of filtering at roof component workstation.

nies the module along the assembly line. At each workstation the crew foreman performs the filtering, determining which information is required from the information packet for the task in hand. Figure 4.6 shows typical information filtering by the wall framing foreman. Figures 4.7, 4.8, and 4.9 show documents received by the plumbing foreman and filtering by the foreman for use in those assembly tasks.

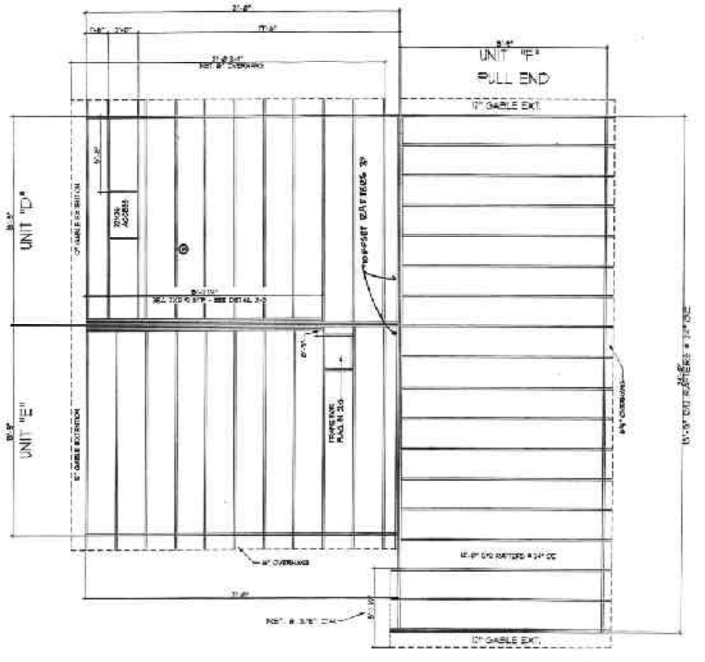


Figure 4.5. Roof framing plan.

OBSERVED SYSTEM DISCONNECTS

Disconnects in the context of this work are areas of the construction process where information exchange or material flow is not meeting performance requirements for the construction system. Disconnects can result in production delays, errors, rework, and other disruptions. The disconnects were identified using a combination of field research and analysis of the process map.

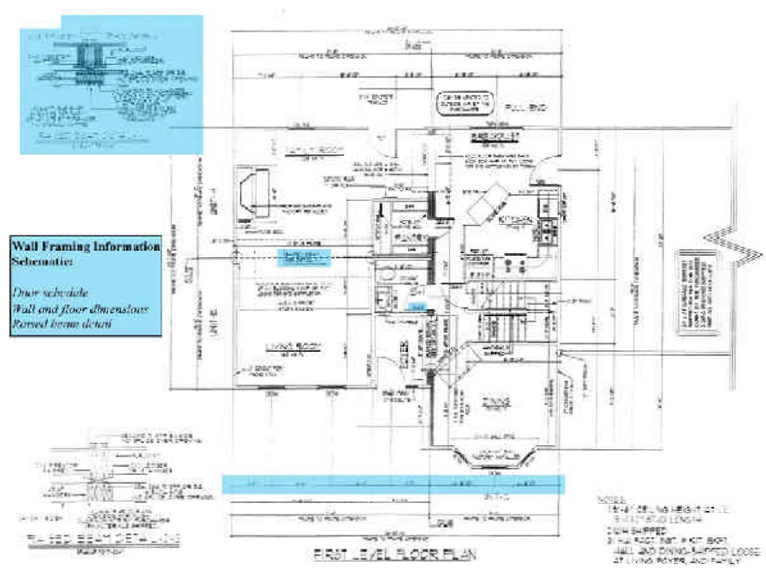
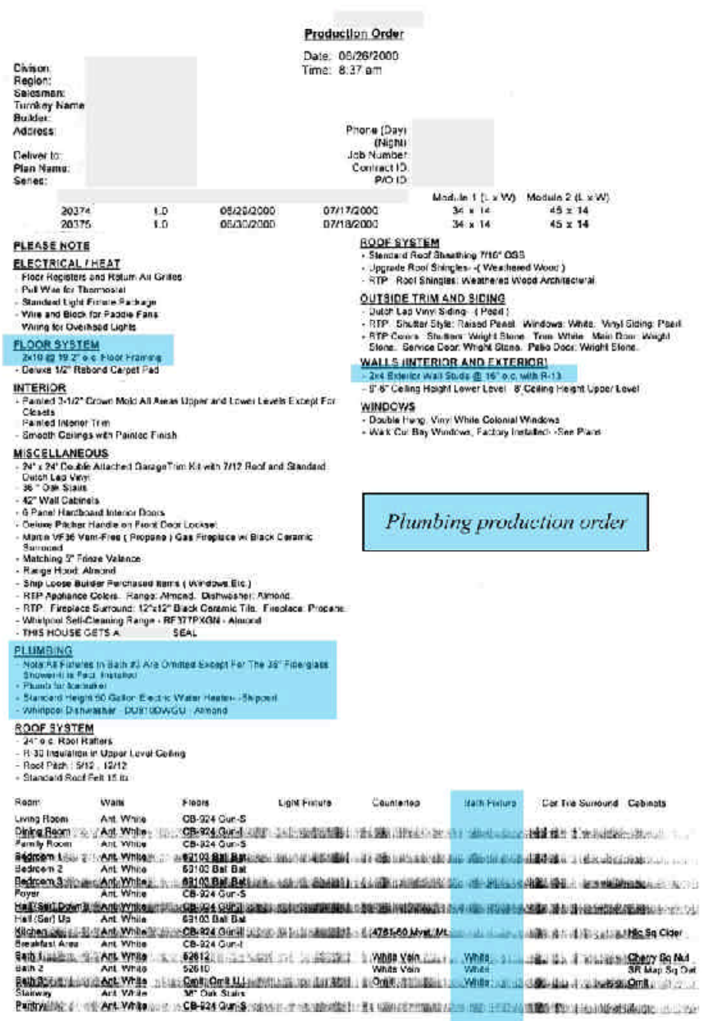


Figure 4.6. Information filtering by wall framing foreman.



Production Order

Date: 06/26/2000
Time: 8:37 am

Divison:
Region:
Salesman:
Turnkey Name
Builder:
Address:

Deliver to:
Plan Name:
Series:

Phone (Day)
(Night)
Job Number:
Contract ID:
P/O ID:

				Module 1 (L x W)	Module 2 (L x W)
20374	1.0	06/29/2000	07/17/2000	34 x 14	45 x 14
20375	1.0	06/30/2000	07/18/2000	34 x 14	45 x 14

PLEASE NOTE

ELECTRICAL / HEAT
- Floor Registers and Return Air Grilles
- Pull Wire for Thermostat
- Standard Light Fixture Package
- Wire and Block for Paddle Fans
  Wiring for Overhead Lights

FLOOR SYSTEM
- 2x10 @ 19.2" o.c. Floor Framing
- Deluxe 1/2" Rebond Carpet Pad

INTERIOR
- Painted 3-1/2" Crown Mold All Areas Upper and Lower Levels Except For Closets
  Painted Interior Trim
- Smooth Ceilings with Painted Finish

MISCELLANEOUS
- 24' x 24' Double Attached GarageTrim Kit with 7/12 Roof and Standard Dutch Lap Vinyl
- 36" Oak Stairs
- 42" Wall Cabinets
- 6 Panel Hardboard Interior Doors
- Deluxe Pitcher Handle on Front Door Lockset
- Martin VF36 Vent-Free (Propane) Gas Fireplace w/ Black Ceramic Surround
- Matching 5" Frieze Valance
- Range Hood: Almond
- Ship Loose Builder Purchased Items (Windows Etc.)
- RTP Appliance Colors. Range: Almond. Dishwasher: Almond.
- RTP. Fireplace Surround: 12"x12" Black Ceramic Tile. Fireplace: Propane.
- Whirlpool Self-Cleaning Range - RF377PXGN - Almond
- THIS HOUSE GETS A SEAL

PLUMBING
- Note:All Fixtures In Bath #3 Are Omitted Except For The 36" Fiberglass Shower-It is Fact. Installed
- Plumb for Icemaker
- Standard Height 50 Gallon Electric Water Heater- -Shipped
- Whirlpool Dishwasher - DU910DWGU - Almond

ROOF SYSTEM
- 24" o.c. Roof Rafters
- R-30 Insulation in Upper Level Ceiling
- Roof Pitch : 5/12 , 12/12
- Standard Roof Felt 15 lb

ROOF SYSTEM
- Standard Roof Sheathing 7/16" OSB
- Upgrade Roof Shingles- -(Weathered Wood)
- RTP. Roof Shingles: Weathered Wood Architectural

OUTSIDE TRIM AND SIDING
- Dutch Lap Vinyl Siding- (Pearl)
- RTP. Shutter Style: Raised Panel. Windows: White. Vinyl Siding: Pearl
- RTP Colors. Shutters: Wright Stone. Trim: White. Main Door: Wright Stone. Service Door: Wright Stone. Patio Door: Wright Stone.

WALLS (INTERIOR AND EXTERIOR)
- 2x4 Exterior Wall Studs @ 16" o.c. with R-13
- 9' 8" Ceiling Height Lower Level. 8' Ceiling Height Upper Level

WINDOWS
- Double Hung, Vinyl White Colonial Windows
- Walk Out Bay Windows, Factory Installed- -See Plans

Plumbing production order

Room	Walls	Floors	Light Fixture	Countertop	Bath Fixture	Cer Tile Surround	Cabinets
Living Room	Ant. White	CB-924 Gun-S					
Dining Room	Ant. White	CB-924 Gun-I					
Family Room	Ant. White	CB-924 Gun-S					
Bedroom 1	Ant. White	63103 Bal Bat					
Bedroom 2	Ant. White	63103 Bal Bat					
Bedroom 3	Ant. White	63103 Bal Bat					
Foyer	Ant. White	CB-924 Gun-S					
Hall (Ser) Down	Ant. White	[illegible]					
Hall (Ser) Up	Ant. White	63103 Bal Bat					
Kitchen	Ant. White	CB-924 Gun-I		4761-60 Myst. Mt.			Hic Sq Cider
Breakfast Area	Ant. White	CB-924 Gun-I					
Bath 1	Ant. White	52612		White Vein	White		Cherry Sq Nut
Bath 2	Ant. White	52610		White Vein	White		SR Map Sq Oat
Bath 3	Ant. White	Omit		Omit	White		Omit
Stairway	Ant. White	36" Oak Stairs					
Pantry	Ant. White	CB-924 Gun-S					

Figure 4.7. Information filtering from production order by plumbing foreman.

Five disconnects were identified in the Builder One system: change order processing and communication, product pricing, production scheduling, plumbing/electrical work, and the roofing workstations.

- Change orders represent a significant disconnect in the Builder One construction system. Significant rework and waste can occur when a change order is accepted after the requisite work has been completed. In the current process, once the original information packets have been distributed, it takes several days to process a change order and communicate the information to the correct workstations. This delay has the potential to lead to loss of time and rework if the change order is not received in time. Reducing time for informing the production process of changes would considerably alleviate this problem.

- Product pricing is another area of disconnect. Changes, special material requests, and nonstandard items take several hours to process and price. Establishing partnerships with key suppliers that provide easy access to pricing or provide a stable price over time would overcome this disconnect. This step could streamline pricing and increase speed and accuracy of pricing to the customer.

- A disconnect is also apparent in production scheduling. The present system manually produces schedules that are forwarded by office

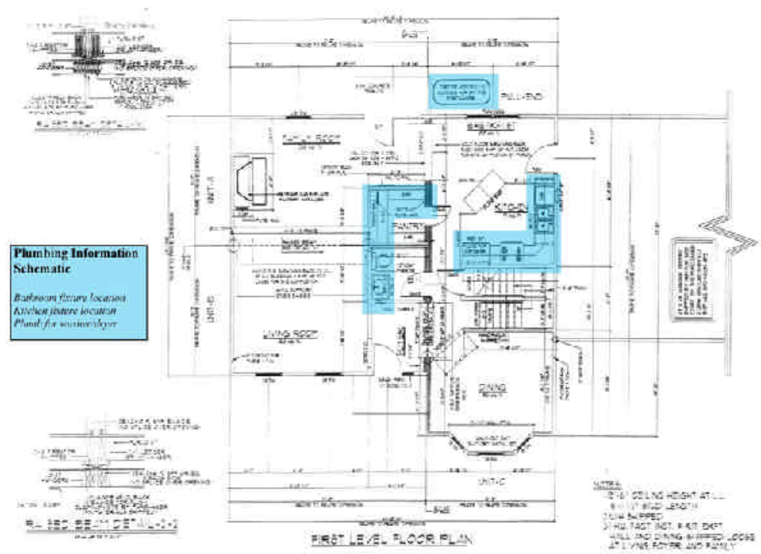


Figure 4.8. Information filtering from floor plan by plumbing foreman.

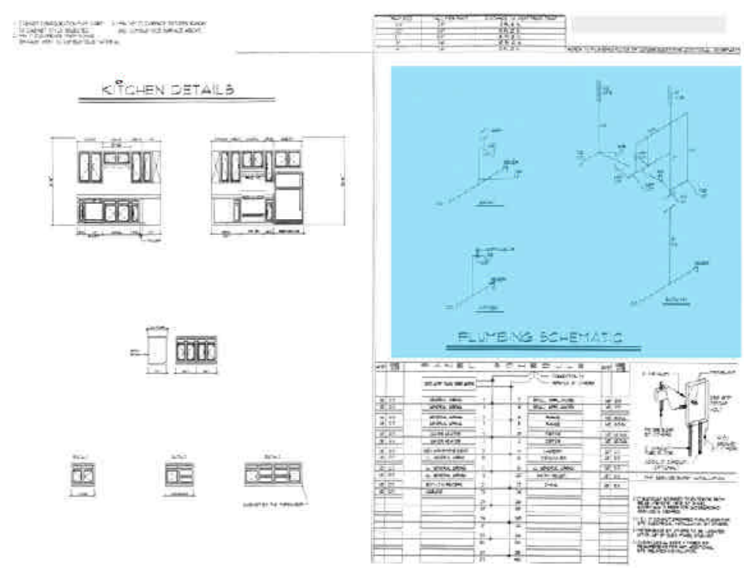


Figure 4.9. Information filtering from kitchen details by plumbing foreman.

mail to every department. These schedules quickly become outdated as they are based on plant productivity, foundation completions, and customer requirements. A closer to real-time production scheduling system would keep departments informed about changes in production schedules and enable purchasing agents, component plants, and module plants to monitor production more closely and better meet production demands.

- Electrical and plumbing trade workstations in the modular plant appear to be affected by information disconnects. Interviews with crew foremen in the data collection phase revealed that the filtering process of information packets at this station frequently uncover inaccuracies or code violations. When a problem is found, it is rectified in the module being constructed, and the drawings are modified accordingly. However, these problems are not routinely communicated back to the engineering department for rectifying in future module designs. A design feedback system would help designers rectify these problems and reduce the burden on trades people at the workstation.

- The roof framing station suffers from a different type of information disconnect than those described above. Observations of the information package and interviews with the foreman revealed a filtering problem that results in difficulty at this workstation. The roofing crew must filter through approximately 15 documents to get the information needed for construction. The roofing crew requires information on roof pitch, roof line, and coordination activities with other workstations. Such a substantial filtering operation requires considerable effort that significantly increases the chance of error and causes production problems for the crew. Significant improvements may be possible by performing filtering at the design stage and simplifying the documents used for construction

BUILDER TWO

Figure 4.10 shows the process map for the Builder Two construction system. The process map identifies information and material flows within the system. The main focus of the map is identifying information necessary to build the structure.

In contrast to Builder One, Builder Two does not itself perform any work on the homes it builds; rather it negotiates contracts with subcontractors on a project-by-project basis. Builder Two is transitioning to use the "Builder Program" to manage the construction and delivery of homes. In this program, a nearly autonomous "builder" controls two or three subdivision projects located in the same geographical region. The "builder" handles the majority of contracts, marketing, and advertising. Each "builder" in this program essentially becomes a construction company with its own superintendenting staff, sales staff, secretarial staff, etc. This report concentrates on the building process from customer order to turnover of the house. This process is relatively similar, regardless of the management system in place at the subdivision level.

The process map indicates the information paths and material paths in the ideal system. This system is essentially linear in nature and is based on a fixed-time, 89-day schedule for house construction (Figure 4.11). The linear system requires the builder to place orders with contractors once particular milestones are reached. The information flows to contractors and material suppliers using a number of standard documents. For example, the job initiation order (Figure 4.12) records the information for the superintendent and subcontractors for a particular house. The Builder Two information sheet (Figure 4.13) records all options selected by the customer for the information of subcontractors. Information also flows through informal communication in the form of superintendent calls to subcontractors. These informal and indirect information flows are also indicated on the process map. The two types of information flow in this system do not necessarily operate together, causing many of the disconnects highlighted in the next section.

OBSERVED SYSTEM DISCONNECTS

The 89-day schedule (Figure 4.11) is based on a five-day work week. In theory, the schedule should allow all those involved in the house con-

Figure 4.10.foldout Process map for Builder Two. Click here for link to map

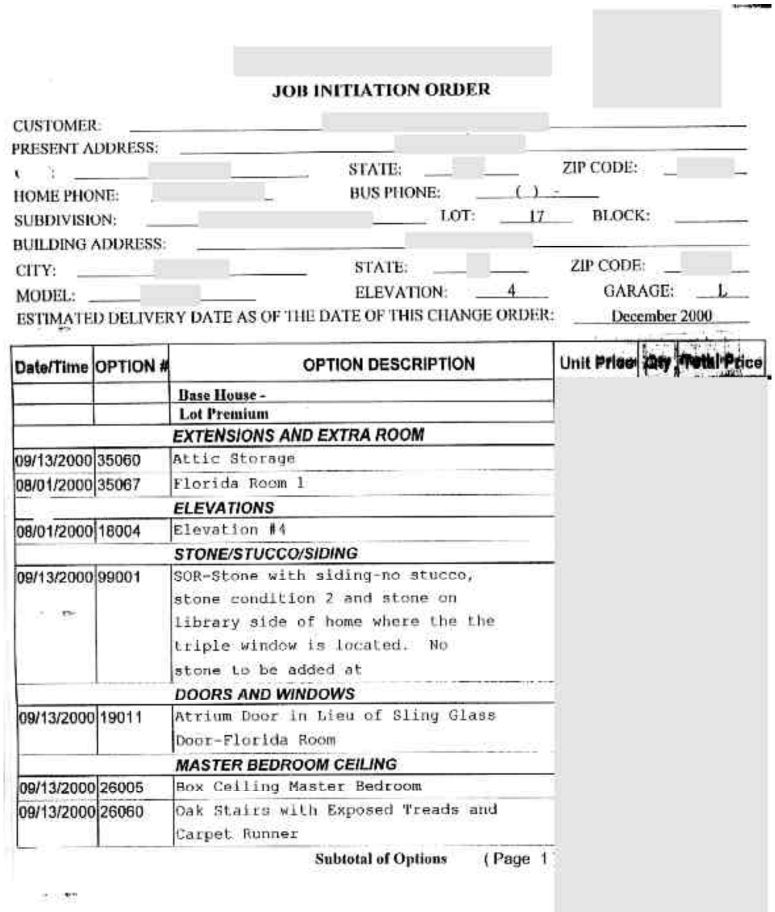
89 Day Schedule   FEBRUARY

UPDATED 6/1/98

		Lot# Closing Day	05-Jan	08-Jan	15-Jan	14-Jan	15-Jan	16-Jan	21-Jan
	STAKING	1	21-Aug	26-Aug	03-Sep	02-Sep	03-Sep	04-Sep	09-Sep
F	EXCAVATION	2	22-Aug	27-Aug	04-Sep	03-Sep	04-Sep	05-Sep	10-Sep
O	DIG FOOTINGS	3	25-Aug	28-Aug	05-Sep	04-Sep	05-Sep	08-Sep	11-Sep
U	FOOTING INSPECTION	5	27-Aug	02-Sep	09-Sep	08-Sep	09-Sep	10-Sep	15-Sep
N	POUR FOOTINGS	7	29-Aug	04-Sep	11-Sep	10-Sep	11-Sep	12-Sep	17-Sep
D	FORM WALLS	8	02-Sep	05-Sep	12-Sep	11-Sep	12-Sep	15-Sep	18-Sep
A	INSPECT WALLS	10	04-Sep	09-Sep	16-Sep	15-Sep	16-Sep	17-Sep	22-Sep
T	POUR FOUNDATION	11	05-Sep	10-Sep	17-Sep	16-Sep	17-Sep	18-Sep	23-Sep
I	WATERPROOF AND DRAIN TILE	14	10-Sep	15-Sep	22-Sep	19-Sep	22-Sep	23-Sep	26-Sep
O	FOUNDATION INSPECTION	14	10-Sep	15-Sep	22-Sep	19-Sep	22-Sep	23-Sep	26-Sep
N	BACKFILL/ROUGH GRADE	15	11-Sep	16-Sep	23-Sep	22-Sep	23-Sep	24-Sep	29-Sep
	UNDERGROUND PLUMBING	15	11-Sep	16-Sep	23-Sep	22-Sep	23-Sep	24-Sep	29-Sep
S	PLUMBING INSPECTION	16	12-Sep	17-Sep	24-Sep	23-Sep	24-Sep	25-Sep	30-Sep
C	PREP SLAB	16	12-Sep	17-Sep	24-Sep	23-Sep	24-Sep	25-Sep	30-Sep
H	INSPECT SLAB	17	15-Sep	18-Sep	25-Sep	24-Sep	25-Sep	26-Sep	01-Oct
E	POUR SLAB	18	16-Sep	19-Sep	26-Sep	25-Sep	26-Sep	29-Sep	02-Oct
D	WATER/SEWER	19	17-Sep	22-Sep	29-Sep	26-Sep	29-Sep	30-Sep	03-Oct
U	WATER/SEWER INSPECTION	19	17-Sep	22-Sep	29-Sep	26-Sep	29-Sep	30-Sep	03-Oct
L	ROUGH LUMBER DROP	20	18-Sep	23-Sep	30-Sep	29-Sep	30-Sep	01-Oct	06-Oct
E	SET STEEL	20	18-Sep	23-Sep	30-Sep	29-Sep	30-Sep	01-Oct	06-Oct
		20	18-Sep	23-Sep	30-Sep	29-Sep	30-Sep	01-Oct	06-Oct
	1ST FLOOR DECK	21	19-Sep	24-Sep	01-Oct	30-Sep	01-Oct	02-Oct	07-Oct
	1ST FLOOR WALLS	24	24-Sep	29-Sep	06-Oct	03-Oct	06-Oct	07-Oct	10-Oct
	2ND FLOOR DECK	27	29-Sep	02-Oct	09-Oct	08-Oct	09-Oct	10-Oct	15-Oct
	2ND FLOOR WALLS	32	06-Oct	09-Oct	16-Oct	15-Oct	16-Oct	17-Oct	22-Oct
	EXTERIOR SHEATHING	35	09-Oct	14-Oct	21-Oct	20-Oct	21-Oct	22-Oct	27-Oct
	ROOF TRUSSES	38	14-Oct	17-Oct	24-Oct	23-Oct	24-Oct	27-Oct	30-Oct
F	ROOF PLY	38	14-Oct	17-Oct	24-Oct	23-Oct	24-Oct	27-Oct	30-Oct
R	CORNICE/WINDOWS/EXT. DOORS	38	14-Oct	17-Oct	24-Oct	23-Oct	24-Oct	27-Oct	30-Oct
A	BLOCKOUT/SET STAIRS	40	16-Oct	21-Oct	28-Oct	27-Oct	28-Oct	29-Oct	03-Nov
M	INSTALL ROOFING	40	16-Oct	21-Oct	28-Oct	27-Oct	28-Oct	29-Oct	03-Nov
E	GARAGE DOORS	42	20-Oct	23-Oct	30-Oct	29-Oct	30-Oct	31-Oct	05-Nov
	ROUGH HEAT	43	21-Oct	24-Oct	31-Oct	30-Oct	31-Oct	03-Nov	06-Nov
S	FIREPLACE	44	22-Oct	27-Oct	03-Nov	31-Oct	03-Nov	04-Nov	07-Nov
C	ROUGH PLUMBING	45	23-Oct	28-Oct	04-Nov	03-Nov	04-Nov	05-Nov	10-Nov
H	FRAME PUNCH	46	24-Oct	29-Oct	05-Nov	04-Nov	05-Nov	06-Nov	11-Nov
E	ROUGH ELECTRIC	47	27-Oct	30-Oct	06-Nov	05-Nov	06-Nov	07-Nov	12-Nov
D	ENERGY SEAL	48	28-Oct	31-Oct	07-Nov	06-Nov	07-Nov	10-Nov	13-Nov
U	FIREINSPECTION	49	29-Oct	03-Nov	10-Nov	07-Nov	10-Nov	11-Nov	14-Nov
L	INSULATE	49	29-Oct	03-Nov	10-Nov	07-Nov	10-Nov	11-Nov	14-Nov
E	INSULATION INSPECTION	51	31-Oct	05-Nov	12-Nov	11-Nov	12-Nov	13-Nov	18-Nov
	PRE-DRYWALL ORIENTATION	51	31-Oct	05-Nov	12-Nov	11-Nov	12-Nov	13-Nov	18-Nov
	START SHEETROCK	52	03-Nov	06-Nov	13-Nov	12-Nov	13-Nov	14-Nov	19-Nov
	BRICKWORK	53	04-Nov	07-Nov	14-Nov	13-Nov	14-Nov	17-Nov	20-Nov
	EXTERIOR PAINT	53	04-Nov	07-Nov	14-Nov	13-Nov	14-Nov	17-Nov	20-Nov
	SHEETROCK COMPLETE	54	05-Nov	10-Nov	17-Nov	14-Nov	17-Nov	18-Nov	24-Nov
	TAPE DRYWALL	55	06-Nov	11-Nov	18-Nov	17-Nov	18-Nov	19-Nov	25-Nov
	SAND DRYWALL	61	14-Nov	19-Nov	01-Dec	26-Nov	01-Dec	02-Dec	05-Dec
	BLOWN INSULATION	62	17-Nov	20-Nov	02-Dec	01-Dec	02-Dec	03-Dec	08-Dec
	SIDING	62	17-Nov	20-Nov	02-Dec	01-Dec	02-Dec	03-Dec	08-Dec
	INTERIOR PRIME	62	17-Nov	20-Nov	02-Dec	01-Dec	02-Dec	03-Dec	08-Dec
	INTERIOR TRIM CARPENTRY	64	19-Nov	25-Nov	04-Dec	03-Dec	04-Dec	05-Dec	10-Dec
	POINT-UP DRYWALL	66	24-Nov	01-Dec	08-Dec	05-Dec	08-Dec	09-Dec	12-Dec
	INTERIOR PAINT	68	26-Nov	03-Dec	10-Dec	09-Dec	10-Dec	11-Dec	16-Dec
	INSTALL KITCHEN	69	01-Dec	04-Dec	11-Dec	10-Dec	11-Dec	12-Dec	17-Dec
	MIRRORS/SHELVING	71	03-Dec	08-Dec	15-Dec	12-Dec	15-Dec	16-Dec	19-Dec
F	CERAMIC FLOORS/VINYL BATHS	71	03-Dec	08-Dec	15-Dec	12-Dec	15-Dec	16-Dec	19-Dec
I	APPLIANCE DELIVERY	72	04-Dec	09-Dec	16-Dec	15-Dec	16-Dec	17-Dec	22-Dec
N	VINYL/HARDWOOD FLOORING	72	04-Dec	09-Dec	16-Dec	15-Dec	16-Dec	17-Dec	22-Dec
A	PLUMBING FINAL	73	05-Dec	10-Dec	17-Dec	16-Dec	17-Dec	18-Dec	23-Dec
L	ELECTRIC FINAL	74	08-Dec	11-Dec	18-Dec	17-Dec	18-Dec	19-Dec	29-Dec
	HVAC FINAL	75	09-Dec	12-Dec	19-Dec	18-Dec	19-Dec	22-Dec	30-Dec
S	ROUGH PUNCH-OUT	75	09-Dec	12-Dec	19-Dec	18-Dec	19-Dec	22-Dec	30-Dec
C	ROUGH CLEAN	75	09-Dec	12-Dec	19-Dec	18-Dec	19-Dec	22-Dec	30-Dec
H	FINAL PAINT	76	10-Dec	15-Dec	22-Dec	19-Dec	22-Dec	23-Dec	02-Jan
E	CARPET	76	10-Dec	15-Dec	22-Dec	19-Dec	22-Dec	23-Dec	02-Jan
D	PRE-WALK INSPECTION	78	12-Dec	17-Dec	29-Dec	23-Dec	29-Dec	30-Dec	06-Jan
U	PUNCH-OUT PRE-WALK	79	15-Dec	18-Dec	30-Dec	29-Dec	30-Dec	02-Jan	07-Jan
L	FINAL CLEAN	80	16-Dec	19-Dec	02-Jan	30-Dec	02-Jan	05-Jan	08-Jan
E	FINAL INSPECTION	82	18-Dec	23-Dec	06-Jan	05-Jan	06-Jan	07-Jan	12-Jan
	CUSTOMER ORIENTATION	83	19-Dec	29-Dec	07-Jan	06-Jan	07-Jan	08-Jan	13-Jan
	SETTLEMENT DATE RE-WALK	85	23-Dec	02-Jan	09-Jan	08-Jan	09-Jan	12-Jan	15-Jan
	FINAL CLEAN	86	29-Dec	05-Jan	12-Jan	09-Jan	12-Jan	13-Jan	16-Jan
	PM RELEASE	86	29-Dec	05-Jan	12-Jan	09-Jan	12-Jan	13-Jan	16-Jan
	SCREENS & SERVICE	86	29-Dec	05-Jan	12-Jan	09-Jan	12-Jan	13-Jan	16-Jan
	FINAL INSPECTIONS	88	02-Jan	07-Jan	14-Jan	13-Jan	14-Jan	15-Jan	20-Jan
	SERVICE PRE-WALK	88	02-Jan	07-Jan	14-Jan	13-Jan	14-Jan	15-Jan	20-Jan
	SERVICE SIGN OFF	88	02-Jan	07-Jan	14-Jan	13-Jan	14-Jan	15-Jan	20-Jan
	CUSTOMER ORIENTATION	89	05-Jan	08-Jan	15-Jan	14-Jan	15-Jan	16-Jan	21-Jan

Figure 4.11. **The 89-day schedule.**

struction to determine the stage of the house and predict future activities involved in the construction. The schedule, however, is difficult to update and alter, leading to considerable information disconnection between the sales office, the field staff, and subcontractors. It is unclear at any particular time whether the subcontractors, for instance, are working from the 89-day schedule, an informal schedule that rests with the superintendent, or their own schedule based on gathering direct information from the site. There is an information disconnect between the management schedule and the field schedule. Scheduling from the subcontractor's perspective

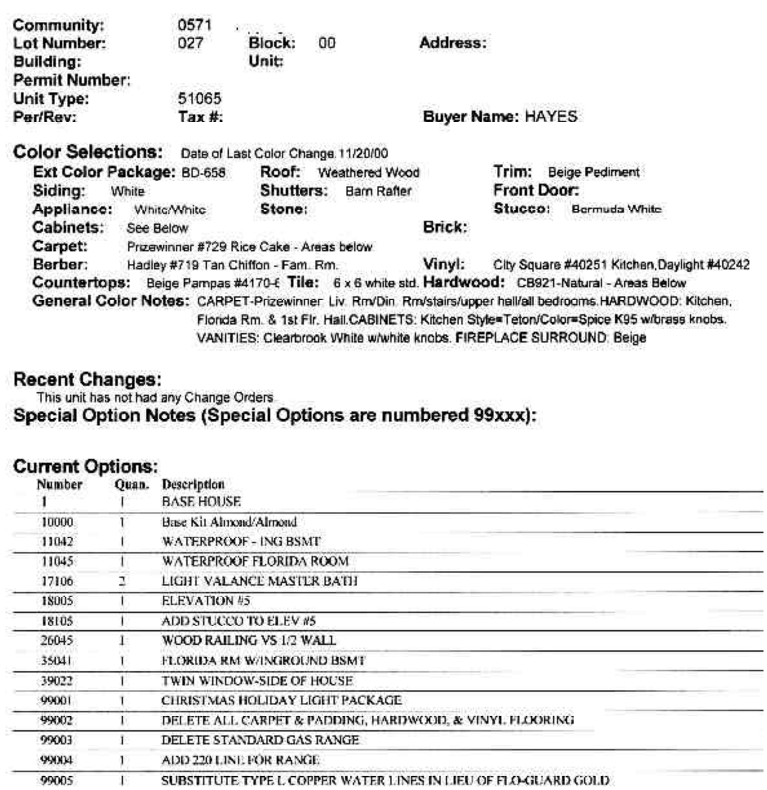


JOB INITIATION ORDER

CUSTOMER:
PRESENT ADDRESS:
STATE: ZIP CODE:
HOME PHONE: BUS PHONE: ( ) -
SUBDIVISION: LOT: 17 BLOCK:
BUILDING ADDRESS:
CITY: STATE: ZIP CODE:
MODEL: ELEVATION: 4 GARAGE: L
ESTIMATED DELIVERY DATE AS OF THE DATE OF THIS CHANGE ORDER: December 2000

Date/Time	OPTION #	OPTION DESCRIPTION	Unit Price	Qty	Total Price
		Base House -			
		Lot Premium			
		EXTENSIONS AND EXTRA ROOM			
09/13/2000	35060	Attic Storage			
08/01/2000	35067	Florida Room 1			
		ELEVATIONS			
08/01/2000	18004	Elevation #4			
		STONE/STUCCO/SIDING			
09/13/2000	99001	SOR-Stone with siding-no stucco, stone condition 2 and stone on library side of home where the the triple window is located. No stone to be added at			
		DOORS AND WINDOWS			
09/13/2000	19011	Atrium Door in Lieu of Sling Glass Door-Florida Room			
		MASTER BEDROOM CEILING			
09/13/2000	26005	Box Ceiling Master Bedroom			
09/13/2000	26060	Oak Stairs with Exposed Treads and Carpet Runner			
		Subtotal of Options (Page 1			

Figure 4.12. The job initiation order.



Community: 0571
Lot Number: 027 **Block:** 00 **Address:**
Building: **Unit:**
Permit Number:
Unit Type: 51065
Per/Rev: **Tax #:** **Buyer Name:** HAYES

Color Selections: Date of Last Color Change 11/20/00
Ext Color Package: BD-658 **Roof:** Weathered Wood **Trim:** Beige Pediment
Siding: White **Shutters:** Barn Rafter **Front Door:**
Appliance: White/White **Stone:** **Stucco:** Bermuda White
Cabinets: See Below **Brick:**
Carpet: Prizewinner #729 Rice Cake - Areas below
Berber: Hadley #719 Tan Chiffon - Fam. Rm. **Vinyl:** City Square #40251 Kitchen,Daylight #40242
Countertops: Beige Pampas #4170-€ **Tile:** 6 x 6 white std. **Hardwood:** CB921-Natural - Areas Below
General Color Notes: CARPET-Prizewinner: Liv. Rm/Din. Rm/stairs/upper hall/all bedrooms.HARDWOOD: Kitchen, Florida Rm. & 1st Flr. Hall.CABINETS: Kitchen Style=Teton/Color=Spice K95 w/brass knobs. VANITIES: Clearbrook White w/white knobs. FIREPLACE SURROUND: Beige

Recent Changes:
This unit has not had any Change Orders
Special Option Notes (Special Options are numbered 99xxx):

Current Options:

Number	Quan.	Description
1	1	BASE HOUSE
10000	1	Base Kit Almond/Almond
11042	1	WATERPROOF - ING BSMT
11045	1	WATERPROOF FLORIDA ROOM
17106	2	LIGHT VALANCE MASTER BATH
18005	1	ELEVATION #5
18105	1	ADD STUCCO TO ELEV #5
26045	1	WOOD RAILING VS 1/2 WALL
35041	1	FLORIDA RM W/INGROUND BSMT
39022	1	TWIN WINDOW-SIDE OF HOUSE
99001	1	CHRISTMAS HOLIDAY LIGHT PACKAGE
99002	1	DELETE ALL CARPET & PADDING, HARDWOOD, & VINYL FLOORING
99003	1	DELETE STANDARD GAS RANGE
99004	1	ADD 220 LINE FOR RANGE
99005	1	SUBSTITUTE TYPE L COPPER WATER LINES IN LIEU OF FLO-GUARD GOLD

Figure 4.13. The Builder Two information sheet.

becomes a project-by-project, superintendent-by-superintendent process, leading to scheduling instability, information disconnection, errors, and rework. Builder Two is making some effort to overcome this level of disconnection by publishing the 89-day schedule on the web and updating the schedule on a weekly basis. However, it appears that much of the disconnection results from the fact that the 89-day schedule does not accurately represent the field construction process.

The other major area of disconnection results from customization and changes to the standard house and how these changes move through the process. Failure to communicate change orders to the field in a timely manner is the source of errors, rework, additional costs and delays. Part of this failure may be due to the fact that the sales office is working off the 89-day schedule, but the superintendent is not. For example, based on the 89-day schedule, the sales office may think that the kitchen cabinets have not been ordered or installed and allow the customer to change the kitchen layout when in fact the kitchen is already substantially complete. The other problem results from changes or options not being passed to subcontractors at the appropriate time. This is a two-way problem that could be overcome by having a single, regularly updated source of scheduling information, changes, options, and building information

BUILDER THREE

Figure 4.14 shows the process map for the Builder Three construction system. The process map identifies information and material flows within the construction system. Similar to Builder Two, Builder Three does not perform any actual work on the homes it builds. Builder Three uses an organization based on a project approach. Each subdivision is managed by a superintendent who reports to a project manager responsible for several subdivisions. Project managers report to the division construction manager.

The construction system used by Builder Three is based on the same fixed-time, 89-day schedule used by Builder Two (Figure 4.11), but Builder Three uses an automated schedule system that provides information to superintendents and subcontractors. This system uses a “start line” (recorded phone message) that records lot status and a web-based foundation system that records progress on the 89-day schedule. Both of these automated systems are updated on a weekly basis. The web-based system contains the same information that is contained in the Builder Two schedule but is available for modem access. Subcontractors and superintendents can log on and determine the stage the house is in and schedule their work accordingly. They can also access other details about the house.

Most of the standard documents identified in the Builder Two documents are used in the Builder Three operation with the added information provided by the web-based schedule.

OBSERVED SYSTEM DISCONNECTS

Site visits uncovered several disconnects in the Builder Three construction system, particularly in relation to interactions between subcontractors and site superintendents and between management and site superintendents. There appear to be two main causes for lack of effective information flow between subcontractors and site superintendents. First, subcontractors are brought into the building process before lots are sold or houses begin construction so that quantities, times, and costs are established for "base" models and not particular houses. Most of the homes Builder Three sells have some degree of customization. Frequently, base model plans and documentation that each contractor has do not accurately reflect the custom features that have been added during the sales process. There is an apparent disconnection involving communication of these changes between the sales office, the site, the subcontractor, and the subcontractor's site staff. Disconnects occur at all stages of the process, with the potential to result in errors, rework, and additional delays and costs.

The second disconnect results from a lack of reliability of scheduling information flowing between subcontractors, Builder Three staff, and the web-based schedule. Project schedules often deviate from the 89-day schedule and operate on other schedules. Superintendents then schedule the operation independently, causing disconnects and undermining confidence in the scheduling system. Subcontractors then resort to self-scheduling or waiting for a call from the superintendent, resulting in problems with trade continuity and subcontractors arriving on site before their work area is ready.

Figure 4.14.foldout Process map for Builder Three. Click here for link to map

BUILDER FOUR

Figure 4.16 shows the process map for the Builder Four construction system. The process map indicates information and material flows in the construction system.

The Builder Four construction system differs from those used by other builders in two ways. The first is that the builder never deals directly with the customer. The customer deals with a realtor who works for a different company, so information passes from the realtor to the builder. The second difference is that each housing development is constructed on a build-to-inventory basis. The subdivision becomes in effect a "site factory," where subcontractors move from house to house along a street as in an assembly line. If the next house on the street has not been purchased by a customer, a standard plan home will be built on that site. This ap-

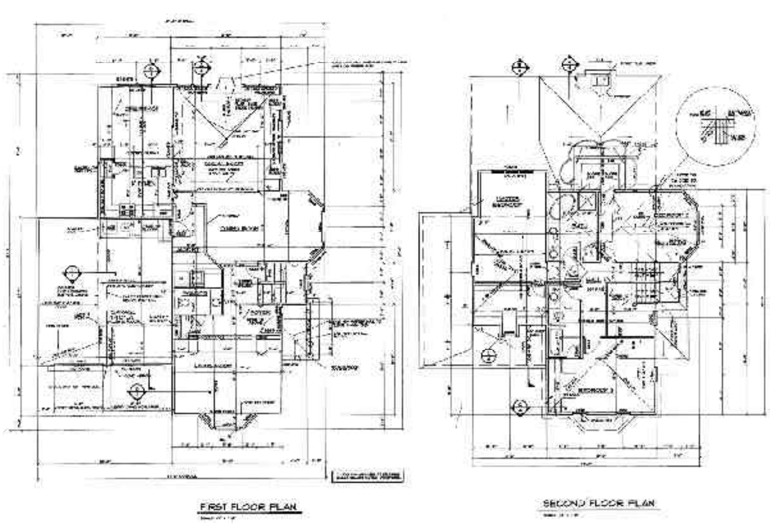


Figure 4.15. Standard floor plan.

Figure 4.16.foldout Process map for Builder Four. Click here for link to map

proach enables the subcontractors to progress smoothly across the entire subdivision, allowing a highly predictable schedule for the subcontractors. Customer-initiated changes are approached as if they were remodeling projects with costs for demolition and rework added as part of the normal cost of the change.

While this approach does not result in the most efficient use of time or money, it allows for rapid build-out of a subdivision project. An additional benefit of this “site factory” approach is that all the primary subcontractors are somewhere on the site all the time, facilitating rapid resolution of system conflict at the subcontractor level and enabling the site superintendent to focus attention on overall production. This process requires the availability of sufficient funds to carry the cost of houses in production but not yet purchased. This “site factory” process depends on a small number of model home plans (four) and standardized specifications. Familiarity with the standard models and specifications allows for highly informal communications between developer, contractor, and subcontractors. Figure 4.16 is a copy of a standard floor plan, and Figure 4.17 is a copy of the standard options. Customization of the home during construction occurs, but with the underlying pricing assumption that demolition and

S–9: STANDARD OPTIONS – ALL MODELS

A CONDOMINIUM

STANDARD FEATURES – EXTERIOR

Foundation – Brick (oversized Colonial)
Exterior – Beaded Cemplank, Painted Colonial Williamsburg Colors
Windows – Double Hung, Tilt Sash, Grill between Glass, Insulated, Screens
Exterior Doors – Insulated
Deck – Salt Treated Wood
25 year Architectural Roof
Exposed Aggregate Driveway & Sidewalk

STANDARD FEATURES – INTERIOR

Fireplace – Masonry Fireplace in Great Room(except , Roughed-in for Gas Logs(logs not included) – (The , ventless with marble surround)
Molding and Trim – Oversized Casing and Base Molding
Oversized Two Member Crown Molding in Dining Room, Living Room, Great Room & Foyer
Two Member Chair Railing in Dining Room, Living Room, Kitchen Nook, Foyer and Powder Room
Ceilings – 9' Ceilings Downstairs (The Kitchen is 8'), Ceiling Upstairs 8', Smooth Ceilings Throughout
Stairs – Oak Treads, Painted Risers, Oak Handrail
Flooring – Oak Flooring in Foyer, Great Room, Dining Room, Living Room, Kitchen, Powder Room; Ceramic Tile in all Full Baths and Utility room; Carpet in all Bedrooms & Second floor Hall
Plumbing – Master Bath – Jetted Tub & A Shower set in Ceramic Tile, Cultured Marble Double Sink Vanity
Second floor Bath – Fiberglass Shower/Tub Combination & Cultured Marble Sink
Kitchen has Double Sink and Garbage disposal
Ice-Maker Hook-up and Copper Water Lines
Cabinets – Raised panel cabinets with Custom Countertops
HVAC – Two Zone Heating & Cooling: Gas Heat First Floor & Heat Pump Second Floor
Gas Hot Water Heater, Gas Line Roughed in for Kitchen Range
Appliances – GE White Appliances
Self-Cleaning Electric Range
GE Dishwasher
GE Space-Saver Microwave
Electrical – Telephone Connections in Kitchen, Great Room & All Bedrooms
Cable Connections in Great Room and Master Bedrooms
Great Room & All Bedrooms Wired & Blocked, Ready for Ceiling Fan
Additional Features – Mirrors in Full Bathrooms, Smoke Detectors, Garage Door Opener, Installed Alarm System; Floored Storage Room on the Second Floor, 2-Car Garage, Pull down stairs to attic

May 2, 2000

Figure 4.17. List of standard options.

-1: CODE COMPLIANCE INSPECTION REQUEST

COUNTY

CODE COMPLIANCE INSPECTION REQUESTS

LOT #

3320 Landing Permit #

1 –

TYPE OF INSPECTION	DATE/TIME CALLED	DATE OF INSPECTON	APPROVED/ REJECTED	NOTES:
Footing	02/09/00	02/10/00	A	Inspection done by ECS Ltd.
1st Foundation		02/23/00	R	See notes on report
1st Foundation		03/24/00	A	
2nd Foundation		04/17/00	R	See notes on report
2nd Foundation		04/20/00	A	
Footing for fireplace		05/10/00	A	See notes on report
Framing	06/19/00	06/20/00	A	
Electrical R/I		06/20/00	A	
Plumbing R/I		06/20/00	R	See notes on report
Mechanical R/I		06/20/00	R	See notes on report
Gas R/I		06/20/00	R	See notes on report
Mechanical R/I ②	06/20/00	06/21/00	A	
Plumbing R/I ②	06/20/00	06/21/00	R	See notes on report
Gas R/I ②	06/20/00	06/21/00	A	
Plumbing R/I ③	06/21/00 @ 9:50 a.m.	06/22/00	A	
Insulation	06/26/00	06/27/00	R	See notes on report
Insulation②	06/27/00	06/28/00	A	
Plumbing – Final	09/14/00	09/15/00	A	
Gas – Final	09/14/00	09/15/00	A	
Mechanical – Final	09/21/00	09/22/00	R	See notes on report
Electrical – Final	09/27/00	09/28/00	A	
Mechanical – Final ②	09/28/00	09/29/00	A	
Final	09/28/00	09/29/00	R	
Final ②	10/04/00	10/05/00	R	See notes on report
Final ③	10/06/00	10/09/00	R	See notes on report
Final ④	10/25/00	10/27/00	R	See notes on report
Final ⑤	11/10/00	11/13/00	A	

Figure 4.18. Sample of code compliance checklist.

rework will be included in the cost of all changes.

The system of construction is linear in nature, and information flows are relatively clear due largely to the familiarity of suppliers and subcontractors with the standard models. In contrast to other site builders, many of the subcontractors have a continuous presence on the site and can observe progress on houses for themselves. Thus, subcontractors rely less on the information system than would be necessary if dispersed. For this reason much of the information flow is informal, visual, and somewhat difficult to capture. The scheduling of deliveries and subcontractor work are superintendent based, with the superintendent calling in requests on an as-needed basis.

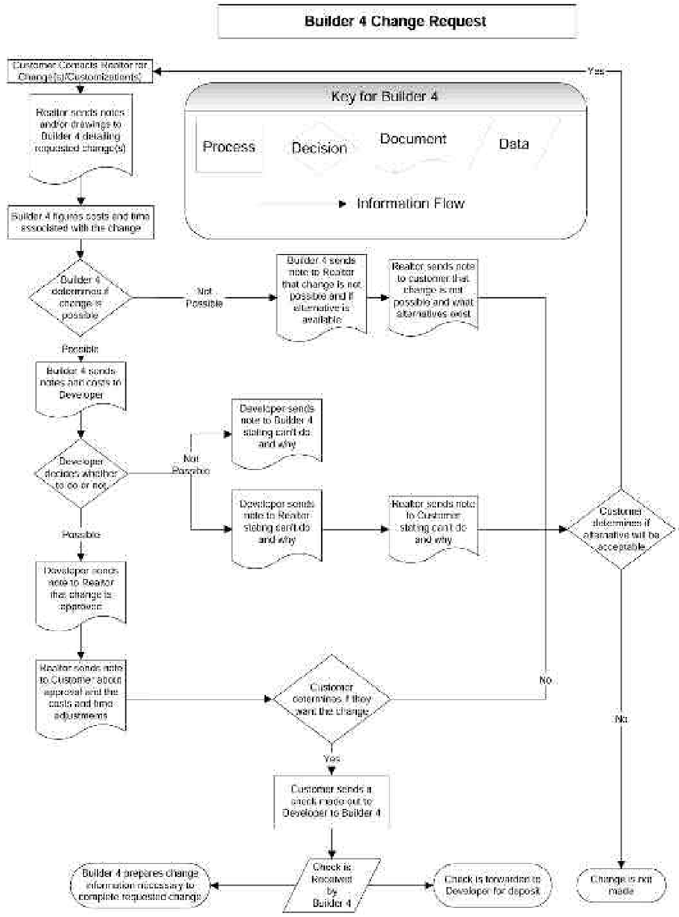
OBSERVED SYSTEM DISCONNECTS

The repetitive nature and flexibility of area assignments in this builders construction system resulted in barely detectable disconnects. Disconnects, when they occur, are overcome by flexibility in area assignments.

Areas of potential disconnect, however, lie in the informal method of scheduling. There is no formal trigger for placing of vendor orders, filing inspection requests, or making subcontractor assignments. Figure 4.18 shows a copy of the code compliance inspection requests.

Change orders are another area of disconnect. The linkage between sales, where the change order usually originates, and the site superintendent,

Figure 4.19. Builder Four change order process map.



who schedules and authorizes work, is somewhat tenuous. The disconnect can happen when the superintendent is unaware that a change order has been issued and fails to take account of that in authorizing work. Figure 4.19 shows the change order process map.

BUILDER FIVE

Figure 4.20 shows the process map for Builder Five. The process map includes the procedures and processes for taking a home from purchase to delivery. While Builder Five is a subsidiary of a larger homebuilder, it was an independent developer until recently. With the new corporate structure came new corporate information systems. However, the systems that the larger builder put in place serve mainly as a means of tracking corporate income and expenditures. That is, they serve to notify the corporate offices of a new contract and track the progress of each house against the master schedule and cost estimates.

To understand the process map in Figure 4.20, it is useful to describe the process by which information is created, processed, and distributed to produce a house. The initial step is decisions made by the buyer in selecting a house design, lot, and any options desired. These are communicated by the sales agent to central office staff for two feedback checks. The first of these checks is provided by the construction manager, who determines the house placement on the lot (left- or right-hand design). The second check is provided by the architect, who checks the house and options for fit on the selected lot and its setback requirements. A determination of fit is then returned to the sales agent and serves as an authorization to draw up

Figure 4.20.foldout Process map for Builder Five. Click here for link to map

a contract with the buyer. Information in this feedback loop is sent by fax to and from the office and is typically accomplished while a buyer waits. The sales agent then draws up a contract of sale and obtains the buyer's signature. The contract is then submitted to the central office for approval and signature by the Director of Sales or Division Manager. Copies are

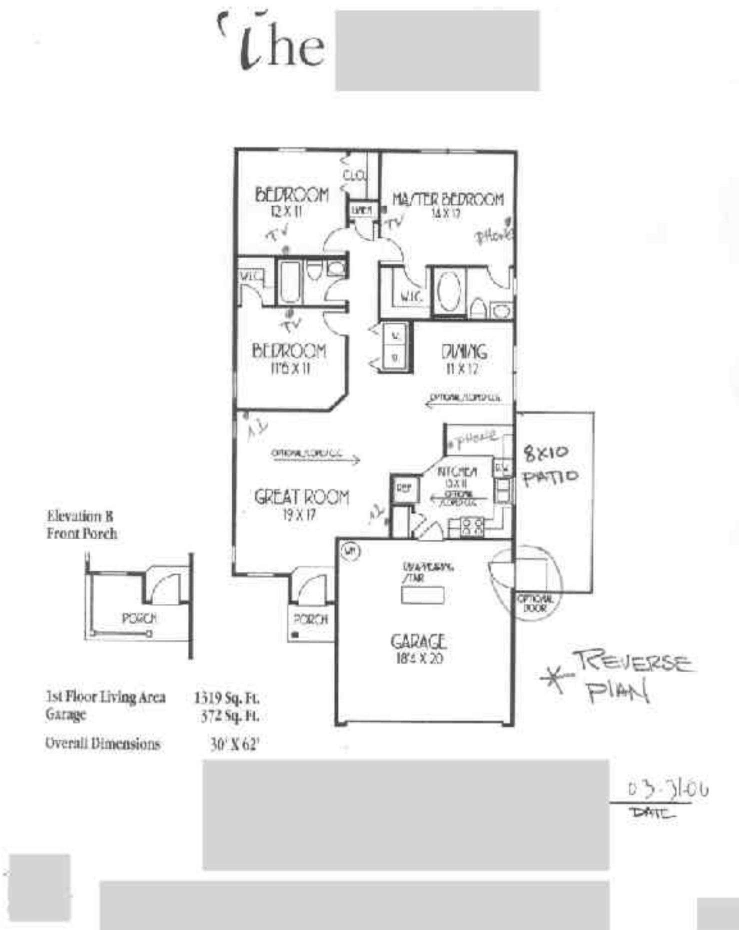


Figure 4.21. Drawings showing hand-marking of options.

provided to the sales closing coordinator and the division manager's administrative assistant for processing. The sales closing coordinator extracts data for tracking loan approvals and provides a copy of the contract to the land development administrative assistant. The land development administrative assistant uses the contract to produce a set of plans for the home. The appropriate drawings (design and orientation) are reproduced, and then all options, including locations, are marked up on the plans by hand (Figure 4.21).

The marked-up plans are then duplicated, and two copies provided to the buyer for approval. When an approved copy is returned, the plans are considered final and start packages, which include the plans and contract, are assembled.

As soon as the closing coordinator receives notification of a loan approval, the start packages are distributed to purchasing and to the superintendent. Purchasing pulls all data from the start package to create the supplier information sheet (Figure 4.22) and the subcontractor information sheet (Figure 4.23). The information sheets identify to each vendor and subcontractor exactly what materials or work are required for the house and identify the prenegotiated associated costs. The information

SUPPLIER INFORMATION SHEET

Date:	April 14, 2000	Date Released to Field:	
Contract Date:	3/31/00	Square Feet (under roof):	1691 HSF
Development:		ot #:	1
Customer:		Supervisor:	
House Plan:	Boston	Elevation:	B
Garage Side:	LH		

SPECIFIC OPTIONS:

1)	Add 8x10 Concrete Pad as shown on plan
2)	Add Optional Garage Side Door
3)	Upgrade Kitchen to 12x12 Tile
4)	Upgrade Foyer to 8 x 8 Tile
5)	Upgrade carpet
6)	Upgrade Kitchen cabinets
7)	Add Garage door opener with remote
8)	Add 3 additional TV outlets
	Standard - Unfinished Garage
	Standard - Textured walls throughout

Figure 4.22. Builder Five supplier information sheet.

SUBCONTRACTOR INFORMATION SHEET

Date:	April 14, 2000	Date Released to Field:	
Development:		Lot #:	1
Customer:		Supervisor:	
House Plan:	Boston	Elevation:	B
Garage Side:	LH		

Siding:	Color:	Sandstone	Type:	Vinyl
Trim:	Color:	Pure White		
Shingles:	Weathered Grey			
Shutters:	Style:	Raised	Color shutters/Front Door:	blue (colonial)
Brick:	Color:	Ship Balast	Size:	
Plumbing:		White		

FLOOR COVERINGS:

Carpet Color:	Upgrade - Equinox - Silver 947
Indoor/Outdoor Carpet	N/A
Kitchen Flooring	Upgrade to 12x12 tile Bergeral - Grout #19 Pewter
Master Bath Flooring	Armstrong 66095 - Initiator
Guest Bath Flooring	Armstrong 66095 - Initiator
Powder Room Flooring	N/A
Laundry Room Flooring	Armstrong 66095 - Initiator
Foyer Flooring	Upgrade to 8 x 8 tile Bergeral - Grout #19 Pewter
Other:	

CABINETS: Upgrade -raised panel white Dover		Knobs:	
KITCHEN TOPS: Nevamar-Navy Matrix MR-3-5T			
INTERIOR PAINT	Dover White	TRIM:	Pure White
MARBLE TOP COLOR:	W/W	MARBLE TOP LOCATION	
ELECTRICAL PACKAGE:		EXTERIOR COLOR:	White
TOTAL CABLE:	5	TOTAL PHONE:	2
APPLIANCES:	White		
FIREPLACE AND SURROUND:			

Figure 4.23. Subcontractor information sheet.

sheets are placed in office mailboxes to be picked up by the subcontractors and vendors. To expedite construction, purchasing immediately places the orders for the trusses and panels, doors and windows, and the lot survey.

The superintendent is provided copies of the contract, as well as two copies of the approved plans. One set is to remain in the file in the field office; the other is for use by the subcontractors and remains in the house

[redacted] RANCH Superintendent-[redacted]
Sq.Ft.-1319 Style-R Lot#[redacted] Permit- Subdivision-[redacted]

Customer-[redacted]	Step	Date Expected		Actual	Gain/Loss
Frame	10	Tuesday	5-16		
Frame	11	Wednesday	5-17		
Frame	12	Thursday	5-18		
Frame	13	Friday	5-19		
Frame	14	Monday	5-22		
Frame	15	Tuesday	5-23		
Deck & Felt Roof	23	Wednesday	5-24		
Deck & Felt Roof	24	Thursday	5 25		
Deck & Felt Roof	25	Friday	5-26		
Rough Plumb	26	Monday	5-29		
Rough Plumb	27	Tuesday	5-30		
Rough HVAC	28	Wednesday	5-31		
Rough HVAC	29	Thursday	6- 1		
Rough Electric	30	Friday	6- 2		
Rough Electric	31	Monday	6- 5		
Roofing/Insulation	34	Tuesday	6- 6		
Insulate Inspection	35	Wednesday	6- 7		
Quality Inspection/Exterior Trim	36	Thursday	6- 8		
Quality Inspection/Exterior Trim	37	Friday	6- 9		
Stock Drywall	38	Monday	6-12		
Hang Drywall	39	Tuesday	6-13		
Hang Drywall	40	Wednesday	6-14		
Tape & Bed	43	Thursday	6 15		
Tape & Bed	44	Friday	6-16		
Drywall Skimmed	46	Monday	6-19		
Drywall Skimmed	47	Tuesday	6-20		
Drywall Ceilings Stippled	48	Wednesday	6-21		
Drywall Sand	49	Thursday	6-22		
Stock Interior Trim	50	Friday	6-23		
Interior Trim	51	Monday	6-26		
Interior Trim	52	Tuesday	6-27		
Interior Trim	53	Wednesday	6-28		
Cabinet Installation	54	Thursday	6-29		
Countertops	55	Friday	6-30		
Countertops / Marble Tops	56	Monday	7- 3		
Exterior & Interior Paint	57	Tuesday	7- 4		
Exterior & Interior Paint	58	Wednesday	7- 5		
Exterior & Interior Paint	59	Thursday	7- 6		
Exterior & Interior Paint	60	Friday	7- 7		
Exterior & Interior Paint	61	Monday	7-10		
Wallpaper	62	Tuesday	7-11		
Ceramic Tile / Bath Vinyl	63	Wednesday	7-12		
Plumbing Finish	64	Thursday	7-13		
Electrical Finish	65	Friday	7-14		
HVAC Finish	66	Monday	7-17		
Clean Up / Sweep Out	67	Tuesday	7-18		
Kitchen Vinyl	68	Wednesday	7-19		
Hardware/Mirrors/Shower doors/Closetmaid	69	Thursday	7-20		
Carpet	70	Friday	7-21		
Carpet	71	Monday	7-24		
Drywall Touch - Up	73	Tuesday	7-25		
Final Clean	74	Wednesday	7 26		
Final County Inspection	75	Thursday	7-27		
Certificate of Occupancy	76	Friday	7-28		
Customer Inspection	77	Monday	7-31		
Punch	78	Tuesday	8- 1		
Punch	79	Wednesday	8- 2		
Punch	80	Thursday	8- 3		
Close	88	Friday	8- 4		

Figure 4.24. Daily schedule.

until completion. The date that the superintendent is given the start package then becomes the start date, and the schedule for the house is determined by the master 80-day schedule, shown in Figure 4.24 During construction, all information used by the subcontractors and vendors is contained in the cost sheets and the plans. The superintendent monitors all progress against the schedule and is responsible for notifying vendors and subcontractors of the dates that materials or work will be required.

OBSERVED SYSTEM DISCONNECTS

Throughout the process from initial sale to construction, there are multiple instances of redundancies of data entry, duplication of data, and missed opportunities for automation and electronic distribution of data.

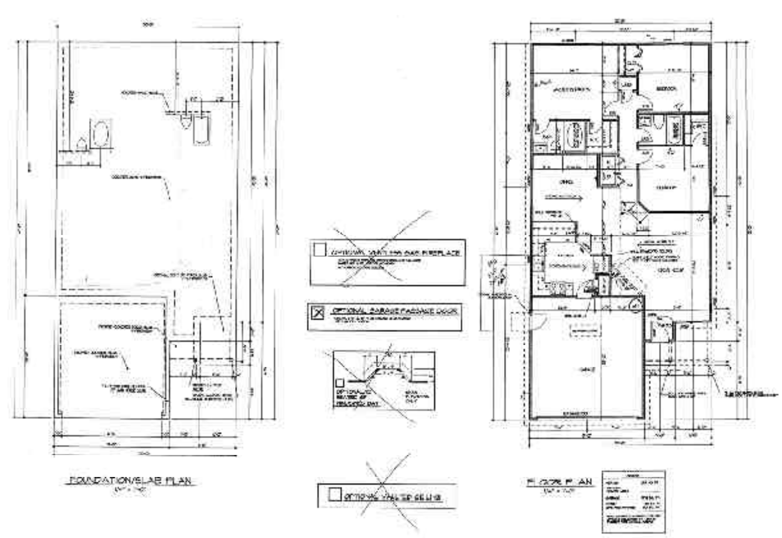
As was discussed in the findings, Builder Five has capabilities of online data transfer and storage with its corporate parent. A large percentage of the data stored on the corporate system is common to all paperwork produced and distributed throughout the local office, yet few personnel have access to the database, and the data entered is never extracted for use locally.

Another observed disconnect occurred very early in the process when the construction manager must determine house placement and the architect must determine if a proposed house will fit on a lot. When the initial engineering is performed for the subdivision, house placement can be built into the site plan; that is, all lots can be designated on the plans as to whether they will accept a right-hand or left-hand house design. In this way the sales agent can state with certainty which orientation of house design must be placed on a particular lot without faxing the main office for a decision. Likewise, the architect's fit check is an exercise in redundancy. To approve a house on a lot, the architect currently draws the lot in AutoCAD, draws in required setbacks, and then drags in the house as an object. While most lots are simple rectangles and the task is quite simple, other lots (especially corner lots and lots on cul-de-sacs) become more complex, not only in their geometry but in the setback requirements. Thus considerable time and effort are invested in the process. By providing the architect (or ideally the sales offices themselves) with digital files of all site plans and all products, a much quicker and more precise method of guaranteeing a fit could be realized.

As was mentioned above, no electronic data is shared by the various players in the process. To further complicate matters, the players typically create unique forms and files to display and track common data. This diversity of documentation makes it difficult for one player to pass information along to another, as the information must first be extracted from the hard copy, reentered into the new document, and printed for use by the next player. This process is not only unnecessarily complicated but also wasteful in terms of time and resources.

Another disconnect comes when the drawings are produced for a proposed house. Current procedure has the land development administrative assistant pull and duplicate a hard copy of the house plans. On this copy buyer identification information is added, along with specifications for the

Figure 4.25. Floor plans with options shown and marked



house, including options selected and locations of phone and cable jacks. To accommodate this system, all house plans are drawn with all options on the plans, either as a detail box or as part of the main drawing. It is therefore necessary to manually mark the plans to indicate whether each option was selected or not and to approximately locate the communications and other items. This system of including a drawing of the option on the plan and relying on a check mark or strike through to indicate its inclusion or exclusion is confusing and prone to human error. For example, see Figure 4.25. Starting each house with a fresh set of electronic drawings and then including on the drawings only those options selected and electronically adding special locations for items would enable the end user to better interpret the information contained on the drawings.

When the purchasing department receives a start package, it produces a set of documents called Vendor Cost Sheets. The sheets spell out to each supplier and subcontractor the construction start date, the model of the house and the lot on which it is to be built, all options to be included, all color and material selections applicable to the vendor, and all prenegotiated costing for the job. These sheets are placed in a series of mailboxes in Builder Five's offices, and each vendor is required to check the box at least weekly for new sheets. This sheet serves as the only official notification that the vendor receives as to what is needed and when work is to begin. A web-based system would serve very well to automate and expedite this process. With accounts in each vendor's name, subcontractors and suppliers could check the web-based system for new jobs, forward information on to their own people or third-party vendors, and monitor what work is reported as complete and payables processed.

... the primary challenge to the processes observed in these five builders is change. Round-the-clock access to current, accurate information describing changes, appropriately filtered and distributed to all affected parties would eliminate the majority of observed disconnects.

All payables for Builder Five are processed out of the corporate office. Invoices are sent to Indianapolis for payment and, once entered into the system, can be checked by accounting department staff in the Builder Five offices. The system used by the corporate parent is set up to detect and reject large deviations in the budget, but deviations of less than 20% are not flagged by the corporate system. This procedure means that local personnel must periodically review all accounts for smaller deviations and determine the cause, justification, and whether a back-charge to the vendor is needed. This step is typically done after the house is completed but before the books close on it. Therefore, finding information on the deviations can be difficult, and getting restitution may be impossible. Automating the system so that all deviations are flagged and brought to the attention of local personnel for verification would greatly reduce the time spent on this function after construction is complete. The system could still be designed to pay those payables that deviate less than 20% from the budget but require timely explanation for deviations in excess of 20% of budget.

CONCLUSION

The five series of data, summarized in the information maps and in the disconnect analysis, provide much fodder for comparative discussions across the builders. Production differences aside, the primary challenge to the processes observed in these five builders is change. Round-the-clock access to current, accurate information describing changes, appropriately filtered and distributed to all affected parties would eliminate the majority of observed disconnects.

Chapter Five: A Comparative Analysis of the Builders in the Case Studies

5

In the five builders observed, many commonalities can be traced in the content of their information as well as the methods by which that information is generated and shared. These common characteristics, not surpisingly, are also the primary disconnects that these builders face and are most likely representative of all builders' main information challenges.

PRODUCTION PROCESSES

The builders in this study all build homes using the same materials palette—2x4 or 2x6 wall studs, trusses or 2x floor and roof members, oriented strand board sheathing for walls and floors, and vinyl or brick siding. All operate on the eastern seaboard of the United States and have product lines ranging from less expensive starter housing to larger, more expensive homes. The builders studied share the same fundamental process:

- Model designs are developed based on marketing information.
- Models are quantified and priced by each subcontractor and supplier.
- Models are marketed to buyers.
- Buyers are allowed to make limited changes.
- Production planning begin upon sales contract signing.
- A superintendent has responsibility for production.
- Schedules are tied to production capacity and cash flow planning.
- Quality assurance is carried out through additional inspections.

INFORMATION TECHNOLOGY

All of the builders use plans developed in a recent version of computer-aided design (CAD) software. These CAD drawings are sent to the field and to suppliers as hard-copy printouts or plots, and when changes are made, new sets of drawings are generated and distributed to all subcontractors and suppliers. As such, the CAD tools operate as a "digital pencil," but, as is the case in much of the design and construction industry , not all the capabilities of the CAD software are used to integrate "front office" sales activity with "back office" order/inventory/scheduling, production, or production scheduling (Fallon, 1999)[1].

This chapter will present the findings of the analysis from chapter four grouped to present similarities and differences observed in the study group.

Typical uses for information technology tools are as follows:

- Use of CAD software to generate drawings of models—All of the builders studied in this project use CAD software to draw and display design information. However, no use is made of parametric design, object orientation, or connection to other data bases. For example, there is no connection of sales information to the CAD system, no automated checking of building regulations, and no connection between design documents and mate rials supply or production planning.

- Use of word processing software to generate contracts, agree ments, and related forms.

- Use of spreadsheets to generate lists, costs, orders.

PROCESS-BASED INFORMATION

The builders in this study depend on similar means of communication to formally transmit information about the purchase, changes, options, and schedules to suppliers and subcontractors. A list of document and drawing types is included in Appendix A. Each builder depends on a project manual of some kind which describes the model purchased, its orientation (right- or left-handed or reversed), the lot options purchased, and changes requested at time of purchase. These are incorporated with the sales agreement and typically forwarded to the engineering/purchasing departments for feasibility and pricing. When feasibility and pricing are complete, the sales contract is executed and forwarded to project managers for production scheduling/planning. Schedules and production planning documents are manually forwarded to all departments. Builders offering a limited product line operate with fewer documents because the subcontractors have learned the requirements for each model. As buyer choice increases, the drawings and documents required to produce each model also increase, and the filtering of these documents by participants in the building process becomes more complex.

Nomenclature has become a problem for Builder Three because a model name is carried over from one year to the next, incorporating changes, so suppliers/subcontractors cannot determine which model year design they are pricing or building.

Builder One attaches a full set of drawings, purchase documents, and quality assurance checklists to the house on the assembly line, so as it moves from workstation to workstation, there is a complete reference set attached. The site-based builders have varying methods of distributing and updating the project information, varying from the previously discussed web-based system to pigeonhole mailboxes for each subcontractor in the main office. Direct information systems in place generally function well for the initial startup of construction. The weakness of all the direct information systems studied is customer-initiated change orders.

A change order is frequently initiated by the buyer's contacting the sales agent to price a proposed change. The sales agent checks the production schedule to see if the work has progressed to the stage where demolition and rework or restocking fees are necessary. Builder Four uses a process where it is likely that demolition and rework or restocking will be required and prices changes accordingly. This approach covers the cost if demolition is necessary and seems to be a profit point if the change can be accommodated without demolition, rework, or restocking.

For most other companies studied, the production schedule in the hands of the sales agent does not necessarily represent the actual progress of the construction. This situation is occasionally due to the sales agent having an out-of-date schedule in hand, but often is due to construction progressing at a more rapid rate than the standard production schedule proposed. (See figures in Chapter 4 for Builders 2 and 5.) Incentive programs for superintendents/builders completing projects ahead of schedule often mean the sales agent is pricing a change assuming (as the schedule in hand proposed) the work has not progressed, but later the superintendent will learn of the change and have to tell the project manager that the cost of demolition, rework, and restocking will have to be borne by the corporation.

FILTERING

This study documented numerous accounts of information filtering—the reinterpretation and/or representation of initial information into another form. Typically, the lead tradesman of a crew has to collect information from the drawings, specifications, and purchase agreement as they apply to the work of the crew. For Builder One, the lead framer has to assemble the necessary information from the following drawings and text documents:

Information required from drawings

Floor plan	Wall locations/dimensions, millwork, door, window locations
Exterior elevations	Window and door heights, overhangs
Framing plan	Floor roof framing direction, bearing wall locations, girder details, stair locations/dimensions, attic access locations/dimensions
Plumbing plan	Tub/shower type (spa, steel tub), access panel locations
Electrical plan	Recessed lighting locations

Information required from text sources

Production order	Location/code, siding type, wall thickness, accessibility required

After extracting this information, the lead framer translates the information into markings on the piece of lumber intended to be the plate, or on the floor sheathing to locate partitions, door openings, etc. The framing crew then assembles the primary framing, while the lead framer marks locations for blocking to support window treatments, cabinetwork, grab bars, etc.

Filtering occurs most often between the superintendent or trade crew leader and the laborers tasked with executing a specific portion of the work. Historically, and confirmed in this study, the filtering task has required the leader to:

- glean pieces of relevant information from multiple sheets of draw ings and specifications,
- check these pieces of information against the change orders to verify they represent the most current thinking about the project,
- verify that the materials, tools, and labor needed to conduct the work are available,
- plan the work according to the stages of production,
- verify the state of completion of construction and systems in close proximity to the work to be done, identify conflicts, meet with leaders responsible for the conflicting work, arrange resolution, and
- represent these findings in conversation, sketches, and mark ings on the work-in-progress. During this study, production team leaders were observed reading the drawings and production or ders and translating the information into simple diagrams and quantities on note paper, which was then attached to the appropriate workstation as the day's assignment of work.

While not all these tasks can be simplified with the application of existing information technology, many can be. The conventions of drawing—site plan, floor plan, elevation, schedules, and details—have been in use for generations. While these were adequate to support the construction of single-contract structures, they do not readily lend themselves to the complexities found in contemporary construction, with dozens of subcontracts and hundreds of suppliers and bidders. Current drawing conventions are organized primarily to support the bidding/pricing process. The industry formally names them "bid documents." The successful bid package is then assembled with the contract forms, named "contract documents," and transferred in multiple copies (recovered from unsuccessful bidders) to be handed off to the lead builder or construction manager to execute the work.

Drawing conventions today (for example, the American Institute of Architects layer guidelines) do recognize primary subcontracts, grouping the drawings into civil, architectural, mechanical, and electrical sections. Within each section an effort is made to group the primary information needed by major subcontracts and suppliers, e.g., windows and doors, finishes, millwork, foundations, framing, roofing, plumbing, heating and cooling, electrical power, lighting, communications.

While this conventional organization of information speeds the bidding/estimating process, it does little to support the actual production of the work. Intensive effort must be invested by the leader of each subcontracting group to ensure its work will be able to be completed in the most efficient manner possible.

The widespread adoption of CAD programs by the design and construction industry and the convention of representing discrete information on layers which can be made visible or invisible as required at the time of digital or hard-copy plotting offer new opportunities to combine information layers in conventions directly supporting production. As digital plots replace hard copies ("blue prints"), the filtering of information to support bidding, then production, becomes inexpensive and relatively simple: "click on" framing, cabinetwork, plumbing, window treatments, and door and window schedule and generate the "e-plot" for the framing crew. This process produces a set of drawings with **all** and **only** the information needed for the framing crew. Development of layer conventions for production promise to increase productivity, reduce conflicts, improve performance, and reduce cost. Posting of "e-plots" on the web with scripted e-mails sent to any subcontract or supplier affected by a change order has the potential to ensure each member of the construction team to be up to date.

INFORMAL COMMUNICATION

Disconnects between business operations were observed in all builders studied. Frequently disconnection could be found in the communication between departments such as sales and production related to changes or between production and design, where documents were frequently incorrect, but the person making the correction didn't have a means to communicate the perennial errors to the designers.

The disconnects can be classified as

- those pertaining to the "front office" and field personnel, often revolving around schedules vs. progress,
- those pertaining to change orders and schedules already discussed, and
- those pertaining to feedback for quality improvement.

Generally, these are difficulties in getting the right information to the right people in the right form at the right time, a problem of linkage. While often the formal lines of communication and information flow work well across the departmental structure at the **beginning** of production, the information network is often cited as the problem in adapting to changes **during** production. Part of this difficulty is due to the volume of paper accumulated on a project: it is difficult for the parties involved to read through the whole change, find whether they are involved, verify that the current change doesn't supersede a previous change, then verify that the change is going to be implemented. Some builders limit design choices and options and discourage changes, while others have observed that choices, options, and changes are frequently the keys to sales, particularly at higher ends of the residential market.

Within departments, informal lines of communication, indirect information flows, fills in where direct information flows fail. Sharing office and common spaces often make this process work. Depending on these indirect information flows increases the risk of error ("Did you think I said the Smythe house? I meant the Smith house!") and resulting reductions in trust, faith, and goodwill among the parties involved ("You told me this change was going to happen. I ordered the material. Now you tell me it isn't going to be used! Who pays the restocking charge?").

Two problems emerge: communicating the informal findings across departmental lines and being able to discern which "update" in the pile of direct information updates is the most current.

The use of information management tools, common in manufacturing systems such as Enterprise Resource Planning (ERP) tools --integrated databases that support front-end sales integration with accounting, purchasing, inventory, personnel, production and distribution activities--were not found in the organizations studied in this research. The web-based project information and scheduling tool discussed previously is a step in this direction.

CONCLUSION

The challenges to efficient production processes fell into two broad categories, information filtering, and information disconnects.

A primary task for superintendents is finding the information that applies to the specific task at hand, out of all the information making up the project, assembling that information and translating the information into the forms and level of detail appropriate for the personnel actually carrying out the process. These information filtering activities are usually carried out using some combination of document and memory-based information seeking.

Some level of filtering seems inevitable. Any proposed information model must account for the different levels of detail and modes of representations tailored to each group of users. Combining auto-filtering with a high level of information integrity will support a shift away from memory-based filtering ("We always built them this way") and towards the documents as a basis for project information.

Disconnects in information flow can be categorized as content type (i.e., errors, omissions, and changes) and temporal type (i.e., out-of-date information and information not parsed to the schedule or actual state of progress). Temporal disconnects were the most common type observed and are the most likely to be eliminated by the development and implementation of information models encompassing both the corporate office and field-based activities.

The proposed map must specifically address the information disconnects observed in the field by proposing direct connections between disconnected domains. While costs related to disconnects and improperly filtered information were not documented as part of this project, there clearly are costs to the builder, the suppliers, subcontractors, and owners—particularly related to change orders.

Forging solid information flows between departments, suppliers, subcontractors, and field superintendents is necessary for the development of a stable information model.

The most prominent linkages to be formed are the following:

- **Sales to design to production**—This linkage is needed for two reasons, access to up-to-date schedules for accurate pricing of change orders and the full integration of a buyer's selected house plan with options and changes.

- **Production to design/engineering**—Chronic errors in drawings or designs undermine the belief in the accuracy, currency, and completeness of the information presented.

- **Customer service to design to production**—Customer service after the sale is developing from its origins in warranty and problem resolution into a marketing tool and profit center. The proliferation of e-mail among buyers has led a number of builders to include e-mail notifications of regular maintenance items such as shutting off outside hose bibs, cleaning gutters, and furnace checkups. Builders are going so far as to establish permanent web pages for each buyer's house enabling the owners rapid access to shingle and siding specifications used on their house, paint names and types, tile specifications, furnace filter sizes, etc. to support the owners in maintaining and repairing their home (Umlauf-Garneau, 2001)[1]. These "continuous contact" strategies also enable builders to announce new subdivisions or design offerings, remodeling services, and contact owners in anticipation of their next purchase (move up, downsize, retirement village, etc.).

It is of the utmost importance that these linkages be constructed through a central data warehouse to ensure that all information is kept current. The common predilection towards construction of informal information paths can quickly degrade the data integrity and level of integration.

All of the common problems witnessed here give clues as to how an improved information map and new technologies can be put to use on residential construction sites of all sizes.

[1]Fallon, K., 1999 http://www.bentley.com/news/commentary/2000q1/kfallon.htm

6

Chapter Six: An Information Model and Process Mapping for Builder-Specific IT Requirements for the Future

This chapter formulates a generalized information model based on the five builders presented in Chapter Three, the analysis of these builder practices in Chapter Four, and assessment of the information flow, points of filtration, and points of disconnect described in Chapter Five.

SYSTEM GOALS AND APPLICATIONS

Goals for a builder-specific information system differ little from those of large manufacturers or industrial producers:

- Minimize errors in data entry.
- Minimize redundant data forms and entry.
- Make up-to-the-minute data available to all parties needing it across all information domains in the enterprise.
- Provide this data in the language, representational form, and level of detail most effective to the people needing the data.
- Provide data rapidly, accurately, and seamlessly to the normal work operations of the people needing the data.
- Receive progress/updates from field personnel.
- Secure this data from unauthorized use.

To achieve these goals, information must be available and understandable across the many disciplines making up a business enterprise. These disciplines tend to be clustered in separate departments (e.g., accounting or engineering) and are characterized by strong internal operating rules, distinctive terminology, distinctive ways of seeing the information generated internally and well-defined interactions with other disciplinary groups within the enterprise. These disciplinary groupings are treated as information domains in this proposal--bounded parts of a business system having their own structures for data and specific data elements generated in the domain.

This chapter formulates a generalized information model based on data collection of information flow, points of filtration, and points of disconnect in the case studies.

The following proposal for a generalized information model of the production builder process is divided into six domains of information:

- sales/marketing,
- design/engineering,
- purchasing/inventory control,
- production,
- customer service, and
- corporate management.

Applications of this information system span all domains of information in the builder enterprise. Each information domain must be included in the system to avoid costly redundancies in data entry and database systems and to fully implement common terminology across all the information domains in enterprise.

ALTERNATIVE SYSTEMS

Given the large number of people and businesses supporting the builder in the residential construction process, there are two fundamental approaches to an information system.

The first is a decentralized system where each participant in the process (individual or domain) constructs a system that is optimized for the data generated by, the terminology used by, and the forms of information representation customary to that participant. The hand-off of information from party to party requires personnel trained to use the systems, terminology, and form of representation in use by the party each is receiving or transmitting information to. Advantages of this system are it's low initial cost to develop, it's flexibility in being based in digital or hard-copy forms, and the a high degree of optimization within each domain or business developing it's own system. Disadvantages include higher personnel costs, potential information translation difficulties, increased potential for error in redundant data entry, and difficulty in establishing trust in data integrity.

The other approach is a centralized system following an ERP model. This system uses a centralized database surrounded by indexes supporting user groups and filters interpreting data according to the terminology, forms, and representational conventions of the domain. Advantages of this system are it's inherent data integrity, data compatibility, timely access to updated information, increased productivity (less time interpreting and filtering) and information filtering customized to each domain. Disadvantages include higher initial cost in infrastructure and time required to customize the information model to a specific businesses practices.

For these reasons, the following is proposed as the system to support a generalized information model.

PROPOSED SYSTEM OVERVIEW

The proposed system (Figure 6.1) has a data warehouse at its center to make project data available to each information domain in the enterprise. The database will be indexed by lot, model plan, available options, historical data, and buyer-specific information. Supporting indexes of suppliers, subcontractors, and related financial/personnel contacts will also be housed in the central data warehouse.

The central data warehouse is the key to:

- minimizing redundant data entry and associated errors,
- providing up-to-date information to all parties,
- presenting the data in a form and at a level of detail most appropriate to the people viewing/using the data, and
- securing the data from unauthorized access.

Data supporting the business activities of each domain will be automatically represented on the digital forms developed to replace the paper versions currently used.

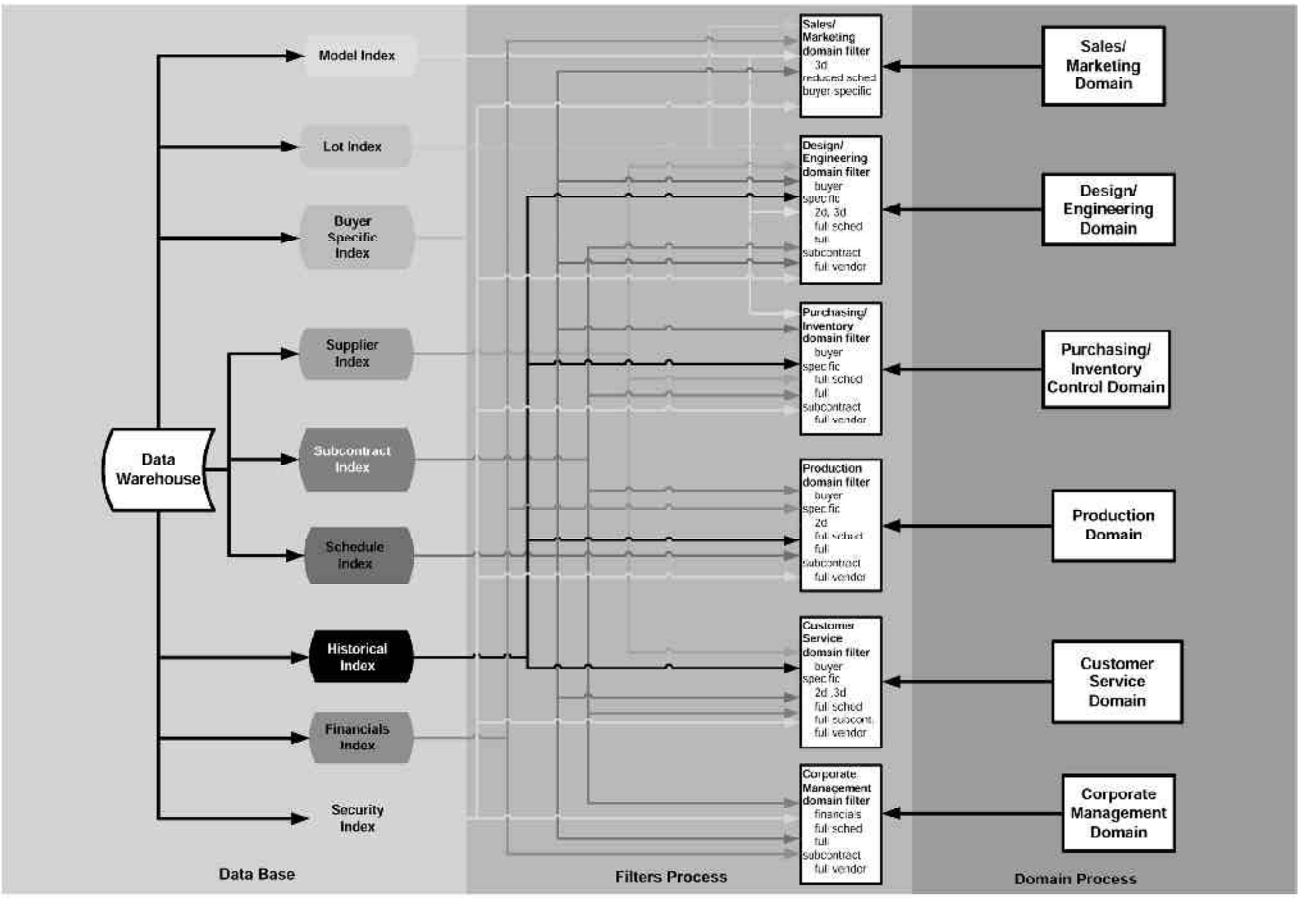


Figure 6.1. Proposed data system

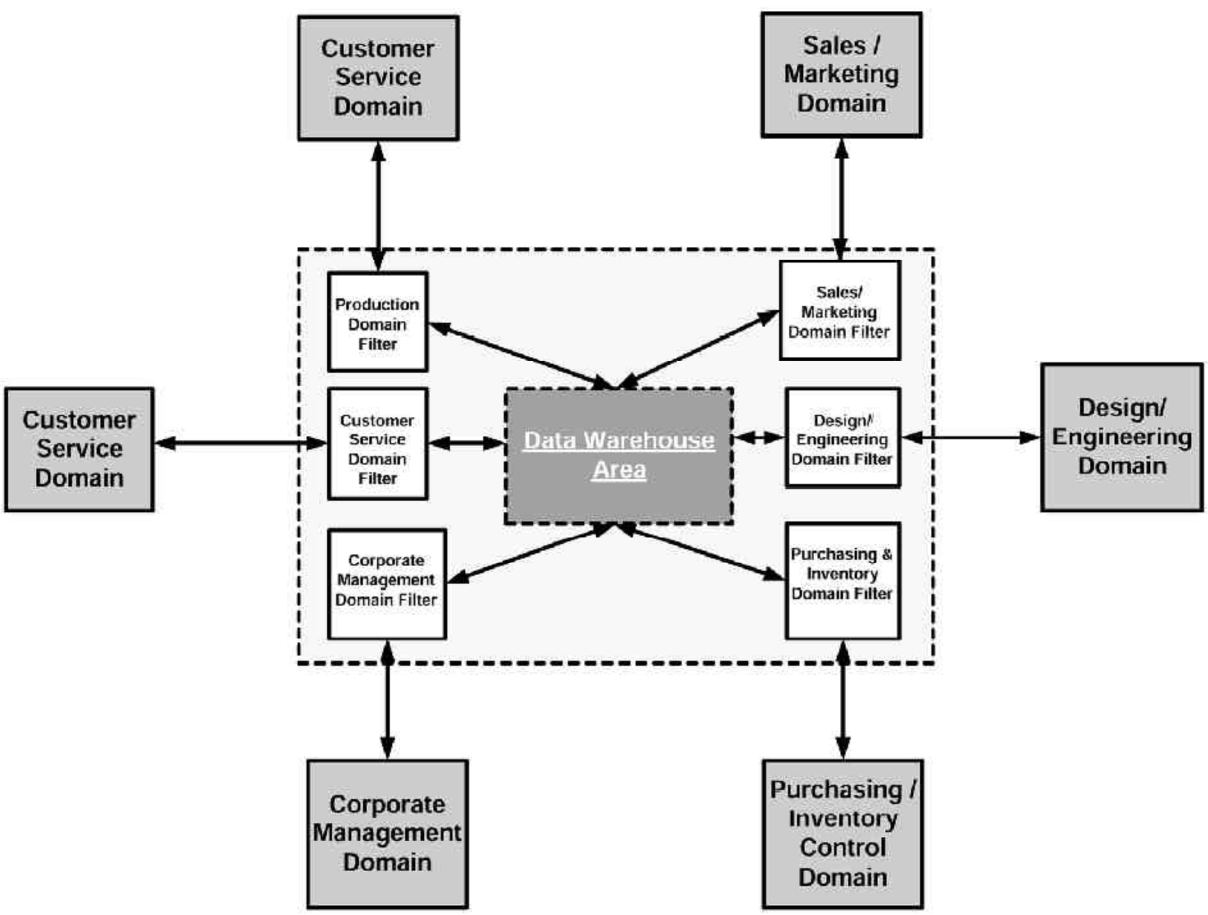
The data warehouse will be accessed by each domain through sets of preestablished queries customized in content and representation to support the level of detail as authorized according to level of access granted to the person initiating the query. The fit between the unique practices of the enterprise, the level of detail available from the data warehouse, and accompanying preconfigured queries is essential to avoid the development of ad hoc "workaround" systems. Engineering this fit will require detailed analysis of each builder's enterprise to tailor the data content and logical rules governing its use to the way the builder conducts business.

PROPOSED SYSTEM MAP

The development of an information system supporting information integration as described in the preceding scenario requires the precise mapping of business policies and practices. This mapping is then translated into the five types of logical components which make up an information model: object types, relationships, operations, data elements, and regulations. Each component is further described by six subcomponents: name, definition, data content, data structure, allowable operations, and data dependencies (Flavin, 1981).

Given the substantial differences in the specific business practices used by builders, a universal data model addressing the specific terminology, practices, rules, and relationships is impossible to construct. Figure 6.2 below diagrams the relationships between the six information domains, their customized information filters and the central data warehouse. All linkages between the domains occur through the data warehouse. This arrangement ensures that each user is working with the most current, most accurate information on the project.

Figure 6.2. Relationships between domains and the data model



Based on the data collected, it is clear that a single model will not be able to encompass the specific business practices of each builder studied. Therefore the following diagrams must be considered as a first effort in developing a generalized information model. It is also clear that complete data modeling will require additional in-depth study of each domain within each building organization and the external connections between the enterprise and its customer, suppliers, and subcontractors.

For each of the studied domains, a generic identification of key people, documents, and objectives has been compiled. A general process narrative, a process diagram, and a listing of key information has been developed. The information linkages between domains have also been identified.

CORPORATE MANAGEMENT DOMAIN

Most production builders have in place information systems supporting corporate management, including accounting, financial, and personnel subdomains. Data collection and analysis work of this project is focused on the process of purchasing, customizing and producing a home. Specific information on personnel, accounting, cash management and profit planning were not included in the data collection activities of this project.

SALES/MARKETING DOMAIN

Process narrative

The buyer and sales representative review plans for the models and lots available in this particular subdivision. The objective of this review is to educate the buyer about quality, availability, design options, and customization possibilities. Buyer decisions regarding options and changes are documented on the model plans, and options are added to the sales agreement. The agreement and model plans are reviewed by the sales manager, who verifies a general time frame for construction and routes the annotated model plans and sales agreement to the design/engineering office. The design/engineering office evaluates the fit between the model and lot chosen, as well as cost and feasibility of the desired changes in combination with the options selected. A set of construction drawings and estimates is produced and forwarded to the sales representative. The sales representative and buyer meet to review the construction drawings and costs related to requested changes, and if all is satisfactory, the buyer signs a sales contract and makes a down payment. If further revisions are required, the construction documents are sent back to design/engineering for further revisions, then reviewed by buyer and sales representative for approval.

Key people:
- Buyer
- Sales representative
- Sales manager
- Engineering representative

Key documents:
- Model plan sheets (printed form, three dimensional model)
- Options information sheets (printed form)
- Marked-up model plans (manual mark-up of printed plan)
- Subdivision plan (printed plan)

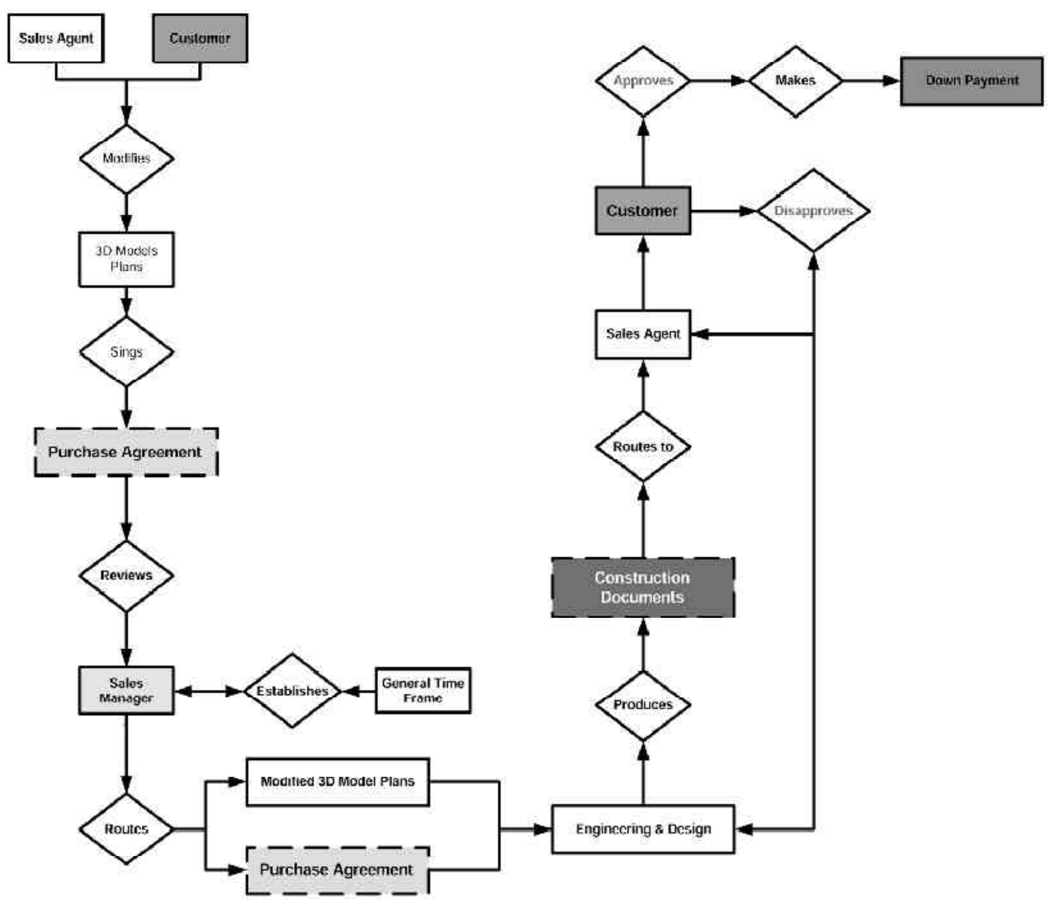
Lot plan (printed plan)
Sales contract (printed form, word processing template)
Down payment contract (printed form, word processing template)
Construction documents with buyers options/revisions

Objectives: Buyer education (extent of customization)
Buyer satisfaction
Sales contract

Key information findings

Purchaser name
Subdivision and lot purchased
Model plan purchased (name, designator number)
Options purchased (name, designator number)
Changes made (room number/name, description of change, change number designation)
Purchase price
Deposit amount, date
Down payment amount, date
Financing approval amount, date
Sales representative name
Development manager approval, construction release date
Preconstruction meeting schedule date
Surveyor property description date

Figure 6.3. General process diagram of the sales/ marketing domain



DESIGN/ENGINEERING DOMAIN

Process narrative

Information exchange in the design/engineering domain is seen in two distinct phases. During the initial design/engineering phase, model home designs are developed in accordance to market trends, engineered for regulatory compliance across the market region, named (designated), and added to the builder's product line. Once part of the standard product line, the design is modified/updated to incorporate option and change trends in the buyers and lessons learned during production which offer savings in material, labor, or coordination between subcontracts. The development of model plans "from the ground up" is not a regular occurrence in the design/engineering information domain.

The day-to-day information flow through the design/engineering domain is triggered by the interaction between sales/marketing representative and the buyer in the sales/marketing domain. Information initiating the production of construction documents for a specific buyer on a specific lot is transmitted to the design/engineering domain in a purchase agreement and a model plan annotated with the options selected by the buyer and other desired changes as permitted by the builder. A project file (data record) is initiated, automatically entering information from the purchase agreement to appear on the title block for the production plans.

Key people:
- Buyer
- Sales representative
- Sales manager
- Engineering representative
- Consulting engineer
- Surveyor
- Construction superintendent
- Subcontractor foreman

Key documents:
- Model plan sheets
- Options information sheets
- Marked-up model plans
- Subdivision plan
- Lot plan
- Lot survey
- Sales contract
- Down payment contract
- Construction documents with buyers options/revisions
    - Specifications/tables of quantities
    - Survey/grading plan
    - Footing foundation plan and details
    - First floor framing plan and details
    - Second floor framing plan and details
    - Exterior elevations
    - Electrical plan
    - Mechanical and plumbing plan
    - Detail sheets
    - Option sheets
    - Change order sheets

Objectives: Description of model as customized and with options purchased by owner
Code compliance
Budget compliance
Buyer satisfaction
Sales contract

Key information findings

Information created in this domain:

Model plan purchased (name, designator number)
Preset options purchased (name, designator number)
Construction documents with buyers options/revisions
- Specifications/tables of quantities
- Survey/grading plan
- Footing foundation plan and details
- First floor framing plan and details
- Second floor framing plan and details
- Roof framing plan and details
- Exterior elevations
- Electrical plan
- Mechanical and plumbing plan
- Detail sheets
- Option sheets
- Change order sheets

Construction documents communicating siting and grading on the selected lot, selected options, and changes requested by the owner are produced. These drawing files are sent back to the sales/marketing representative for owner review and acceptance. Once accepted, the drawing files are distributed to the site superintendent, material suppliers, regulatory officials, and subcontractors. These documents may be modified and reissued while the house is under construction. Owner-initiated changes begin with the buyers contacting their sales/marketing representative to propose the change. The sales/marketing representative evaluates the change against the current construction progress schedule. Based on the progress status (ordered/installed), the sales/marketing representative forwards the change to design/engineering for review and costing. Design/engineering forwards the cost to the sales representative for buyer approval. Upon receiving buyer approval, design/engineering assembles the documents necessary to carry out the change and forwards them to purchasing/inventory control for reissue to the affected suppliers, building officials, subcontractors, and site superintendent.

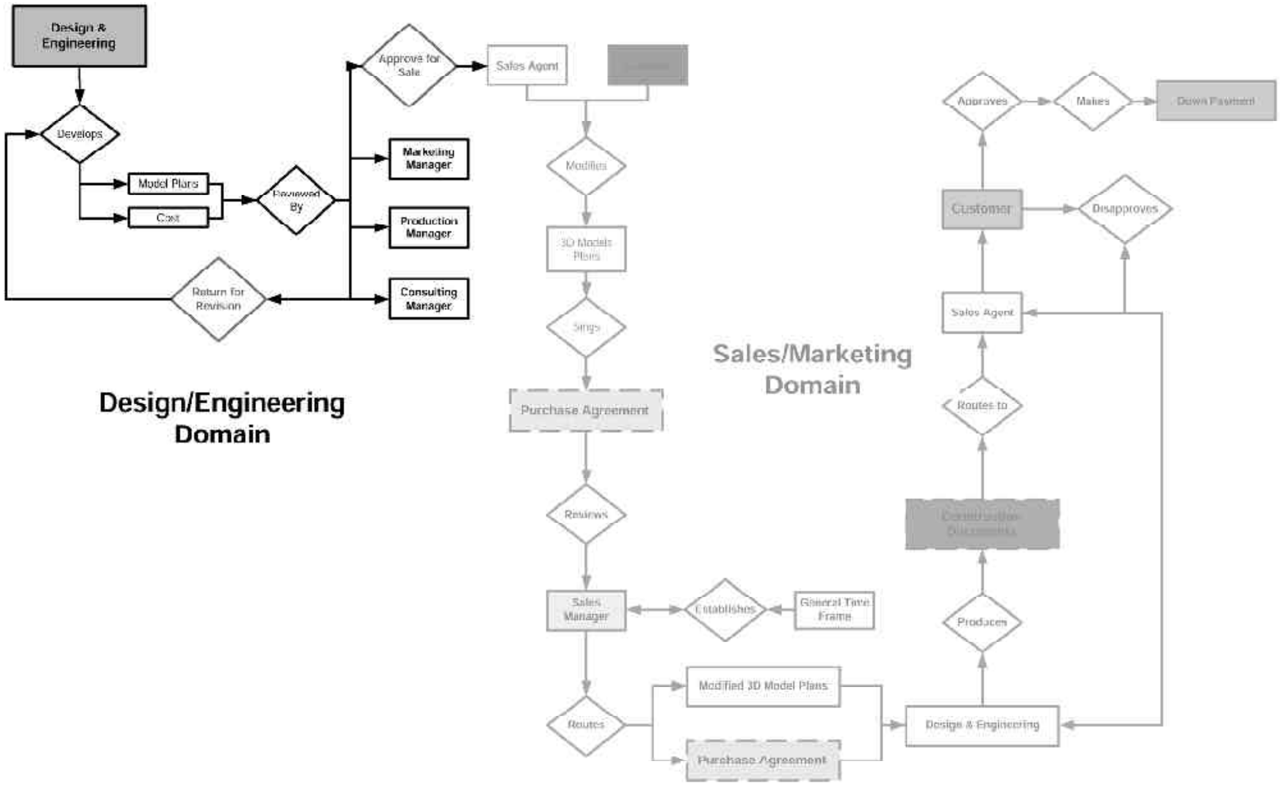


Figure 6.4. Design/engineering domain general process diagram

PURCHASING/INVENTORY CONTROL DOMAIN

Process Narrative

The release for construction notice generates a production schedule which takes into account the time frame for materials and products delivery from suppliers and the availability of subcontractor labor forces. The purchasing agent verifies cost, availability and delivery of custom items, generates purchase orders for all items, and reports any changes in availability of labor and materials to the project manager for schedule revision.

After this initial process, the major activity in the purchasing/inventory control domain is pricing products and materials required for owner initiated changes.

To conduct the work of this domain, the purchasing agent communicates with:

- *the sales representative for owner initiated changes,*
- *the design/engineering domain for materials and product quantities*
- *the subcontractors for each labor operation,*
- *the project manager for schedule updates and status reports,*
- *the customer service domain for final product records and warranty issues.*

Key people: Buyer
Sales representative
Sales manager
Engineering representative
Consulting engineer
Surveyor
Construction superintendent
Subcontractor foreman

Activity in the purchasing/inventory control domain is largely shifted out of office of the builder and into the subcontractor and supplier offices. The form, frequency, and degree of formality of the information flow between builders and their subcontractors/suppliers varies widely from builder to builder.

Key documents: Release for Construction notice
Construction/progress schedule
Sales contract
Construction documents with buyers options/revisions
Specifications/tables of quantities
Survey/grading plan
Footing foundation plan and details
First floor framing plan and details
Second floor framing plan and details
Exterior elevations
Electrical plan
Mechanical and plumbing plan
Detail sheets
Option sheets
Change order sheets

Objectives: Timely purchase and JIT delivery of materials and products necessary to construct the model as customized and with options purchased by owner
Budget compliance
Schedule compliance
Buyer satisfaction
Sales contract closing

Key information findings

Purchase orders
Schedule revisions
Cost revisions
Product specification listing for project-specific "home page" (autofiltered for owner)

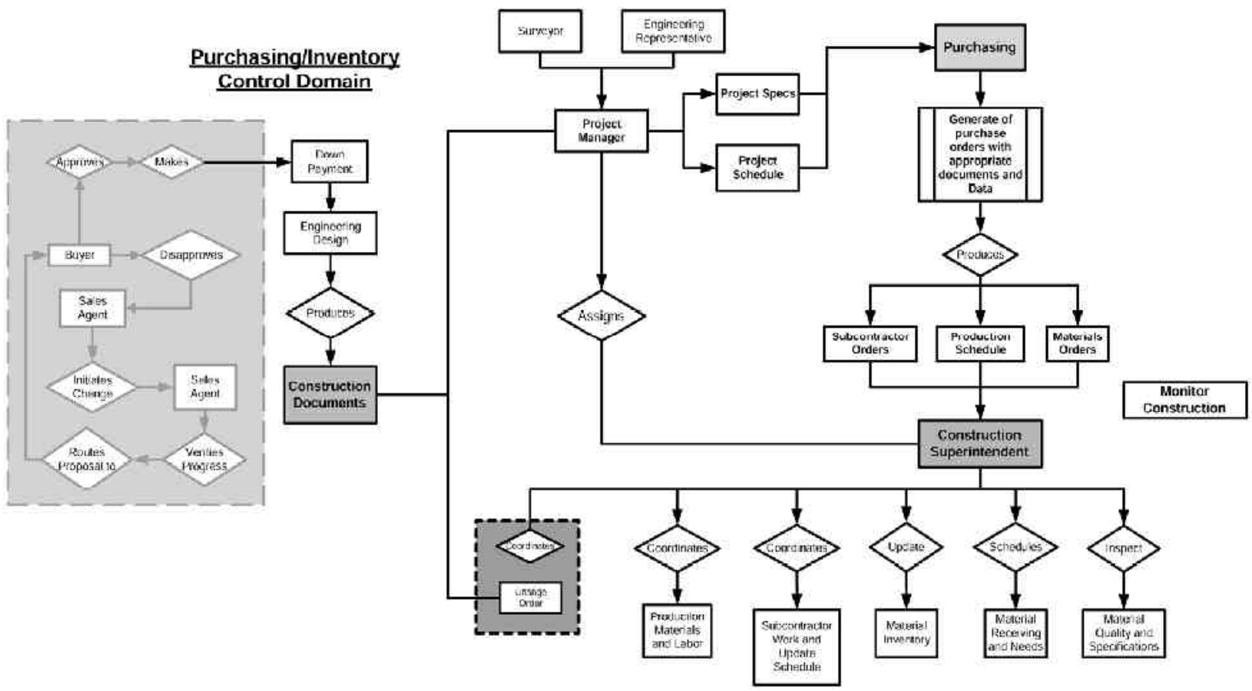


Figure 6.5. Purchasing/inventory control domain general process diagram

PRODUCTION DOMAIN

Process narrative

The release for construction notice generates a production schedule which takes into account the time frame for materials and products delivery from suppliers and the availability of subcontractor labor forces. The construction is assigned to a site superintendent who updates the schedule, resolves questions and conflicts, coordinates changes, secures regulatory approvals, and administers the buyer education program.

The major activity in the production domain is updating each subcontractor on the progress of the work, its state of readiness for the next subcontractor operation, and the state of regulatory approvals. Minor activities challenging the overall process include owner-initiated change orders, delays due to subcontract labor shortages, and delays due to weather.

To conduct the work of this domain, the superintendent communicates with

- *the sales representative to the owner for changes,*
- *the owner directly at interim and final walk-through inspections,*
- *the purchasing/inventory control domain for material and product deliveries,*
- *the subcontractors for each labor operation,*
- *the building regulators for inspections and certifications,*
- *the project manager for schedule updates and status reports,*
- *the design/engineering domain for change resolution, and*
- *the customer service domain for closeout and warranty issue*

Key people:
Buyer
Sales representative
Project manager
Engineering representative
Consulting engineer
Surveyor
Building official
Construction superintendent
Subcontractor foreman

Key documents:
Construction/progress schedule
Lot survey
Sales contract (printed form, word processing template)
Construction documents with buyers options/revisions (printed form of CAD file)
- Survey/grading plan
- Footing foundation plan and details
- First floor framing plan and details
- Second floor framing plan and details
- Exterior elevations
- Electrical plan
- Mechanical and plumbing plan
- Detail sheets
- Option sheets
- Change order sheets

Objectives: Timely construction of model as customized and with options purchased by owner
Budget compliance
Buyer satisfaction
Code compliance
Sales contract closing

Key information findings

Purchase orders
Schedule revisions
Cost revisions
Product specification listing for project-specific "home page" (autofiltered for owner)

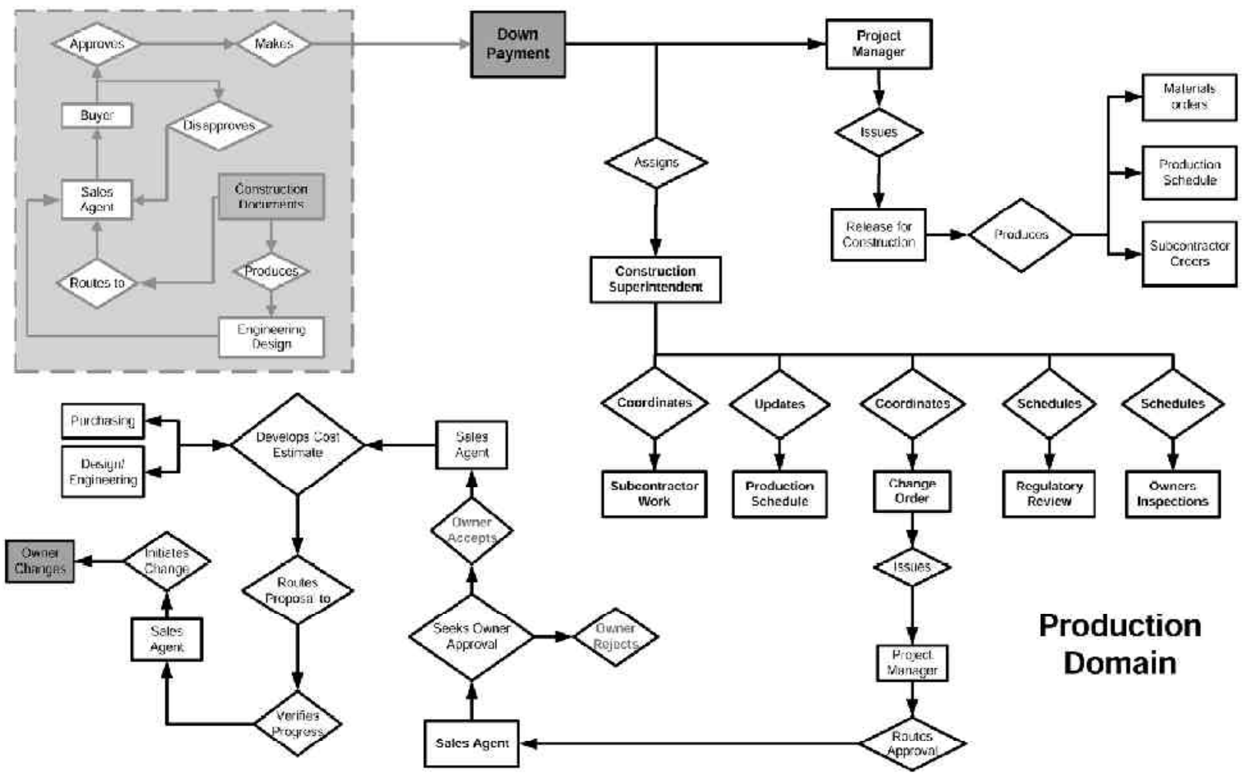


Figure 6.6. Production domain general process model

CUSTOMER SERVICE DOMAIN

Process narrative

In the customer service domain, the information linkages between the buyer the company and the house exist. The process begins with the buyer looking at marketing materials, including house packages, lot availabilities, and available options. Once the sales contract is signed, an individual customer index to the data warehouse is created, giving the customer access to the original agreements, plans, and schedules and keeping the customer informed throughout construction. As construction begins, the customer, superintendent, and sales agent meet onsite to review the staked-out location, model, orientation, and options purchased. During construction, the superintendent will organize a site visit with the owner to review the framing and systems rough-in. Prior to completion, the superintendent will organize a meeting with the owner and customer service representative to identify any items needing correction or adjustment prior to the closing. After the closing, the customer index provides the customer with archival information on the house as built. It also includes access to product information including maintenance details, system operations description, and service representative contacts.

Key people:
Buyer
Sales representative
Sales manager
Engineering representative
Consulting engineer
Surveyor
Construction superintendent
Subcontractor foreman

Key documents:
Construction documents with buyers' options/revisions
Survey/grading plan
Footing foundation plan and details
First floor framing plan and details
Second floor framing plan and details
Exterior elevations
Electrical plan
Mechanical and plumbing plan
Detail sheets
Option sheets
Change order sheets
Product description/supplier list
Product warranty information
Product operation/maintenance information
Systems operations description
Seasonal maintenance description
"Home page for life" configuration
Service representative contact information
Closing documentation
Data archiving in historical index

[1]Umlauf-Garneau, E. 2001. "Home on the Web," Professional Builder, February, 81–84.

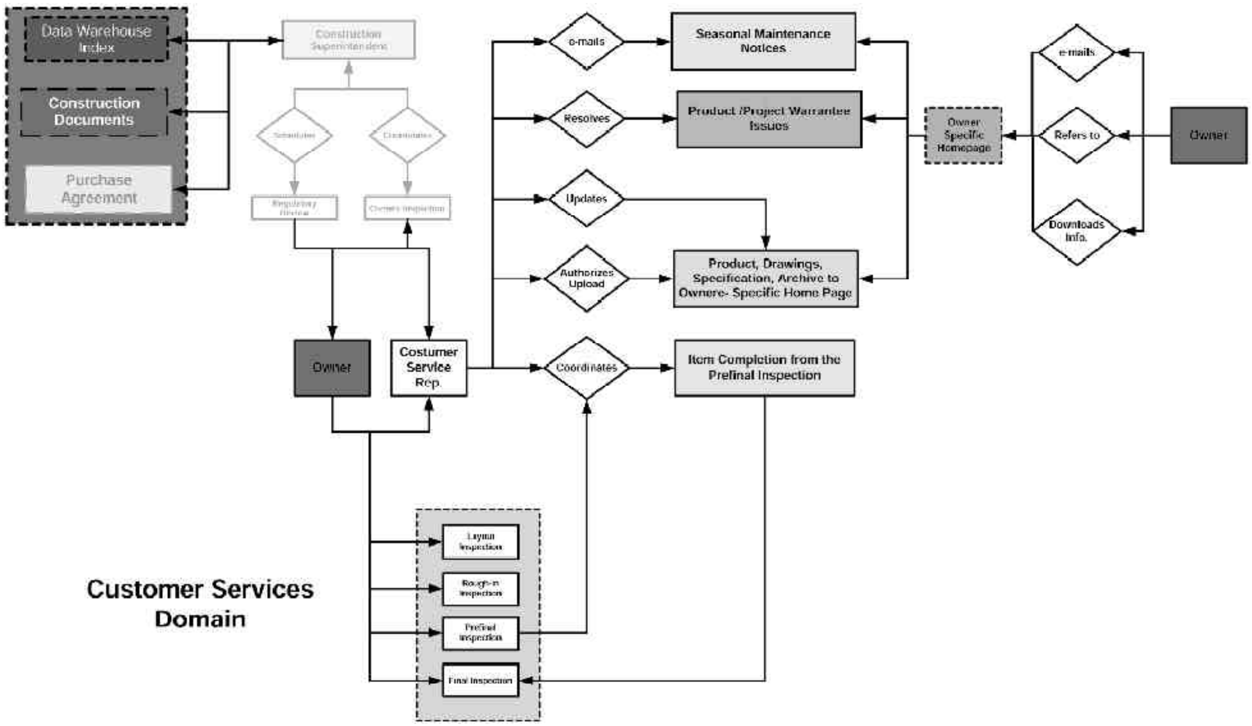


Figure 6.7. Customer service domain general process model

PROPOSED SYSTEM PROCESS:

Application of the model to the process of purchasing, customizing, constructing, and occupying a new home would generally proceed as follows:

Model home designs are developed through an iterative process in which they are digitally passed back and forth between the sales/marketing, design/engineering, purchasing/inventory control, production, customer service, and corporate management domains.

The model's data files are presented to each domain differently, according to its individual practices. For example, the sales/marketing domain sees the model house plan as a three-dimensional graphic, with walk-through capability. The design/engineering domain sees the model as a three-dimensional graphic, as well as a set of two-dimensional plans, elevations, and details. The purchasing/inventory control domain sees the plans as lists and quantities of materials and products drawn from the supplier index in the data warehouse. The production domain sees the model as a set of two-dimensional drawings linked to a schedule of suppliers and subcontractors. The customer service domain sees the model as a three-dimensional graphic with product lists, specifications, and warranty information. The corporate management domain sees the model as a three-dimensional graphic with a compressed schedule, total cost, and profitability projection.

Subdivisions and available lots incorporating survey data, requirements for setbacks and other zoning limitations, and lists of compatible models and orientations are indexed to present each domain with only the data needed about any given lot. A separate index provides ready access to the corporate management domain for inventory and cash flow management.

With model designs and available lots present in the data warehouse, sales/marketing personnel present the three-dimensional models to the clients; digitally mark up the models with options and desired level of customization; and enter name, lot, options, etc. into a buyer-specific index. Options selected are automatically priced, as are any additional costs due to adaptations required for each lot, and a production schedule is generated. Customizing features not included in prepriced options are forwarded through the data warehouse to the design/engineering domain for feasibility, to production for schedule adjustments, then to the purchasing/inventory control domain for pricing, and back to sales/marketing for buyer acceptance.

Upon agreement on cost, options, and schedule, the project is released for production by the digital signature of the project manager. This release automatically triggers a series of events: the purchasing/inventory group receives a purchasing list and schedule, the production group receives a production schedule, the project-specific subcontractor vendors receive their production schedule, and the buyer's web page—showing schedule, their specifically adapted model, product list, and schedule of opportunities for change—is initiated and updated as the production proceeds.

On site, having been notified through their subcontractor-specific web page that the project has been released for production, the surveyors arrive to stake out the house. When a late afternoon thunderstorm inundates the lot, the superintendent pushes the production schedule back one day by clicking a box on his cellular personal digital assistant. All suppliers and subcontractor-specific web pages are updated with this schedule change to maintain just-in-time delivery of materials and labor.

A few days later, the owners look in on their specific web page, observe images of the framing and foundation, and note that the building official has inspected the framing. Their page tells them that this is the last day possible to change the kitchen cabinet order without a restocking charge. The same day the drywall subcontractor looks at his web page and sees that the house has passed inspection and that the drywall has been delivered. The most recent plan change has been posted to the web page; the drywall subcontractor prints it and heads to the site.

Two days later, with an open crew in his production buffer, the electrician checks his web page to see if they can begin final trim on the house. The progress schedule tells him the drywall has been hung, but is not yet taped or painted. He looks to another house on his page and finds it is ready to rough in.

The owners contact their sales agent through their web page and set up a meeting to discuss a change in the patio. The sales agent opens the project-specific web page and notes there are only two days before the tile for the patio will be ordered and that the patio lights have been shipped. During the meeting the owners increase the size of the patio and change it to a Southwestern motif. The sales agent uploads the marked-up three-dimensional model to the data warehouse as a desired change. Uploading as a desired change automatically puts a hold on the tile order, calculates a new cost for the larger patio, requests pricing for the Southwestern motif lights (not in the usual option list), and calculates a restocking fee for the materials in hand (the lights) through the purchasing/inventory control group. The pricing arrives the next business day and is passed on to the owners, who accept all the changes but the new lighting. Plans are automatically updated and issued to the web pages of the specifically affected subcontractors, materials are ordered, and the schedule for the house is pushed back three days. The web pages for all remaining subcontractors and suppliers are automatically updated with the revised schedule, contract amounts, and plans.

With the house nearing completion, the owners are invited via their web page and e-mail to make the final inspection. They walk through with the superintendent, their sales agent, and customer service representative. With a short list of minor items to complete, they schedule the closing date. Two days prior to the closing, the owners are notified that all the items have been corrected, verifiable with digital photos of the corrected items on their web page. The customer service representative schedules a date to familiarize them with the operating systems and regular maintenance items on the house and to personalize the level of interaction between customer service and the owners via their web page. The owners ask for automatic e-mail notices for winter weather preparations and furnace filter changes but decline e-mail notification of special offers on replacement filters, light bulbs, and new subdivision developments.

Three years later, one of the toilet flush valves seems to be stuck partially open. The owners open their web page, find the part number and name of a local supplier (automatically updated from the vendor index in the data warehouse after the last supplier closed down), and place an order for the new part. It arrives the next day. The owners download the step-by-step pictograms for replacement from their web page.

CONCLUSION:

These generalized information maps of the essential domains of information found in the production builders studied in this project map the key parties, their actions, and the objects used to complete those actions during the purchase, design, production, and post-closing services rendered during the house acquisition process. The development and application of an ERP type of model such as this promises to reduce the amount of labor entering redundant data, reduce the errors associated with redundant data entry, increase the response time of the business to changes, increase the pricing accuracy of changes, decrease the contingency costs associated with change to customers, improve accuracy and reduce rework associated with filtering, scheduling, and communication related errors.

These are a first effort towards the construction of ERP type systems for production builders. As such they are limited in the level of detail necessary to fully describe the internal logic used by the parties involved in each action.

Chapter Seven: Conclusions and Recommendations 7

SUMMARY OF FINDINGS

The implementation information technology in the residential construction industry has been slow, partly due to the varying scales and production rates of homebuilders, but perhaps mostly due to diverse business models and practices used by the homebuilding industry. This second phase of *Industrializing the Residential Construction Site* focused on documenting the flow, filtering, and disconnects observed in information flows from five production builders and develops a generalized information model for residential construction.

Field observations documented sophisticated communication channels in the homebuilding enterprises studied in this research. Where impediments were present in the designed flow of information, the builders' personnel had developed "workarounds" to prevent slowing production. As long as the enterprise is staffed with intelligent, committed individuals capable of efficiently working around impediments, production proceeds in a relatively smooth manner.

The most commonly observed challenge to a smooth production process was change. It is clear that change, regardless of the information domain, presented challenges to the designed information flows, communication channels, and people responsible for completing the house. Buyer-requested changes, initiated in the sales and marketing domain, are priced based on the assumption that the project is progressing at the pace indicated on the model 90-day schedule, while incentive programs motivate field personnel to proceed faster than the schedule, resulting in inaccurate pricing and progress delays. The loss of trust in the accuracy of information contributes to a decreasing use of the project documents as a basis for construction. Tradition, memory, and pattern replace information, leading to errors in installation of materials and products and slowing the diffusion of new technologies.

Field observations of this small sample of production builders revealed two categories of information-related impediments to increased production efficiency. We have named these impediments "information filtering" and "information disconnects."

Information filtering is a responsibility that usually falls on the person responsible for the task at hand. The responsible person must know where to find the necessary information, where to find the most current version of this information, and the appropriate level and form of representation of

Disconnects in information flow can be categorized as content type, i.e. errors, omissions, changes and temporal type, i.e. out-of-date information and information not parsed to the schedule or actual state of progress.

this information required to have the work group complete its task. For a field superintendent, this could mean assembling information from dozens of pages of drawings, specifications, and faxes. Once the needed information is collected, this superintendent has to make an informed judgment regarding its accuracy and consistency, weaving the changes into what is known about the status of material orders, progress of the work, expectations of regulatory inspectors, and availability of labor. The superintendent must then represent the information to the purchasing agent, building inspectors, and crew in ways each will understand. Finally, the superintendent must reinterpret the physical manifestation of the work and compare it to the desired outcome as described in text and drawings.

These complex filtering tasks were generally well conducted by the field personnel observed during the data collection phase. It is clear that many of the minor errors leading to delay, cost, and reduction of the productivity of these people responsible for achieving tasks could be resolved by prefiltering information. The information presented to people in this production process should support their communications with their crews allow them to focus their time and energy on accomplishing the task.

The information system model for residential construction places specifically configured filters between the data warehouse and each user in an information domain to present all the information necessary for their work, in terminology and forms familiar to them.

Field observation and data analysis revealed two types of disconnects in the flow of information: content and temporal. Examples of content information disconnects are errors, omissions, and changes. Temporal information disconnects— the more common type encountered—are instances of the available information not accurately describing the state of project progress.

Temporal information disconnects are the most likely to be eliminated by the development and implementation of information models that link corporate office and field-based activities to a central data warehouse. With a central data warehouse as the hub of information, all parties accessing information will be working with the most up-to-date information available. This information model will significantly impact the enterprise's ability to accurately price, schedule, and carry out change orders.

Project data in the central data warehouse is the solid linkage between the domains of information. The solidity of the linkage between tenuously linked or fully disconnected domains is based in a trust that the information is accurate and up to date.

Based on observed disconnects, the most prominent linkages to be formed are:

- **Sales to design to production**—This linkage is needed for two reasons, access to up-to-date schedules for accurate pricing of change orders and the full integration of a buyer's selected house plan with options and changes.

- **Production to design/engineering**—Chronic errors in drawings or designs undermine the belief in the accuracy, currency, and completeness of the information presented.

- **Customer service to design to production**—Customer service after the sale is developing from its origins in warranty and problem resolution into a marketing tool and profit center. The proliferation of e-mail among buyers has led a number of builders to include e-mail notifications of regular maintenance items such as shutting off outside hose bibs, cleaning gutters, and furnace checkups. Builders are going so far as to establish permanent web pages for each buyer's house enabling the owners rapid access to shingle and siding specifications used on their house, paint names and types, tile specifications, furnace filter sizes, etc. to support the owners in maintaining and repairing their home (Umlauf-Garneau, 2001). These "continuous contact" strategies also enable builders to announce new subdivisions or design offerings, remodeling services, and contact owners in anticipation of their next purchase (move up, downsize, retirement village, etc.).

SUMMARY OF THE PROCESS MAP

Based on field observations of designed information flows, filtering activities and information disconnects, the proposal for a generalized information model of the production builder process is divided into six domains of information:

- sales/marketing,
- design/engineering,
- purchasing/inventory control,
- production,
- customer service, and
- corporate management.

These domains are linked to a central data warehouse through information filters that extract the information necessary to the work of the domain, represent it in terminology and forms the domain users are accustomed to, and save updates made in the domain back to the information warehouse (Figure 6.2, p. 50). Key personnel, their actions, and the things supporting their role (forms, drawings, construction) are mapped in relation to the process flows observed in five production builders studied (Figures 6.4–6.7, pp. 52–63).

Applications of this information system span across all domains of information in the builder enterprise. Each information domain must be included in the system to avoid costly redundancies in data entry and database systems and to fully implement common terminology across all the information domains in enterprise.

STEPS IN THE RIGHT DIRECTION

It should be noted that many builders, including those observed in this study, are already taking steps towards implementing information systems and production processes to counteract their existing information disconnects. Many of these include concepts described in the overall process map.

WEB-BASED SCHEDULING

One of the builders studied currently uses web-based production scheduling for each home produced. This site supports the production process, allowing for access to current change orders and schedules any time around the clock. The site reduces production losses to a subcontractor caused by premature arrival of a crew to a particular home site. The costs for such "dry runs" is absorbed by the subcontractor and built into the overhead costs for each project. Elimination of "dry runs" through web-based scheduling is enabling increased productivity and profitability. Ultimately, the web-based information system is intended to allow the superintendent to spend less time on the phone, increasing productivity. The secure site is accessible to the superintendent/builder, subcontractors, suppliers, and project and corporation managers involved in production. The site enables each home, model design designation, buyer option, and production schedule to be viewed online. Production scheduling is initially structured on an 80- to 90-day schedule with incentives to superintendents/builders who complete construction with buyer satisfaction in shorter time periods. Construction progress is reported to the web schedule, enabling all subcontractors and suppliers access to more current information about each house.

SITE FACTORY

Another builder in the study is treating the overall development like an assembly line—only the subcontractors move from lot to lot instead of working in stationary work stations as in a production line. This approach requires the financial capacity to carry the cost of building a house even if there is no buyer at the time of construction. The advantages are in orderly progression of subcontractors from excavation to foundation to framing to finishes with systems woven into each stage. This process is very similar to that developed by the Levitt brothers in the post-war Levittown communities. Like the Levitt communities, this builder offers a small set of designs (six) to the buyers, enabling a high degree of familiarity (simple enough for each subcontractor to keep designs in their heads) honed through frequent repetition. With all the subcontractors on the site each day, system and process conflicts are readily resolved. The resulting benefit is highly efficient production with minimal conflicts between subsystems (and subcontractors), resulting in a higher quality product at a lower price.

This approach requires a rapid turnover of constructed units to keep financing overhead low, a limited number of design models offered to the buyer, and buyers who will pay the costs of demolition and rework to customize their homes.

ON-SITE MANAGEMENT/PRODUCTION INTEGRATION

Builder One operates a state-of-the-art modular manufacturing facility. Having management and production present on the same site has allowed for the refinement of the production process. Components and subassemblies are precut and assembled to allow "just-in-time" delivery to the production line. The combination of traditionally organized plan information and extensive customization of the product mean the leaders of the trade crews must extensively filter the information to provide their crews with only the information germane to their trade.

PROPRIETARY SOFTWARE

Builder Five is a subsidiary of a national homebuilding corporation. As such, it is required to keep the corporate headquarters up to date on contracts, construction starts, and closings. The corporate headquarters has a proprietary database system into which Builder Five inputs information on the home buyer, model, lot, sales price, and closing date. Builder Five does not extract data electronically from this system for its own project information but instead inputs the data manually into its own contract and production process forms. Redundant data entry admits error in terminology and spelling as well as transposition of data between contracts. The larger opportunity lost in redundant data entry into spreadsheets and word processing files is the ability to track trends in buyer trends, costs, change orders, productivity, with integrated data analysis common in larger industries.

3-D MODELING FOR SALES

Builder One is the only builder in this study to implement three-dimensional visualization tools in each of its sales locations. Virtual models are toured, modified, and purchased in sales centers that also include representative prototypes to enable the buyer to conduct firsthand inspection of the houses. The virtual models are the only three-dimensional representations of the house in the owner sees. After the initial sales meeting and contract signing, the buyer is presented with two-dimensional drawings for verification of options and specific engineering of changes.

At this time the three-dimensional models are not linked to the CAD files made to support production activities. This stage of separation between “front office” sales activities and “back office” production activities is similar to the earliest 1989–1994 stages of e-commerce: customers could see the catalog, but orders and production controls were not integrated with purchases.

Parametric modeling—the linkage of three-dimensional models with two-dimensional plans—shows great promise in integrating sales and change order modifications with production drawings. Object orientation—the use of graphic objects with “intelligence”—shows similar promise in integrating the production drawings with purchasing, inventory, and production capacity scheduling.

CONCLUSION: ROLES AND RESPONSIBILITIES OF KEY PLAYERS

Successful implementation of information systems that depend on application beyond management layers must not add to the challenges of producing the house. Specific tasks related to updating information in the system must be simply accomplished at a level of detail that is appropriate to the actual use of the system. Recognition of the inherent differences in the focus of office-based (process-orientated) vs. the field-based (action-oriented) activities of the builder enterprise must underpin any enterprisewide information system development.

As such, future research must be sure to look at the ways in which current production methods, means, and information exchanges affect the adoption of new information technology systems.

Next steps toward the development of information systems to underpin the industrialization of the residential construction site include:

- the development of more detailed information maps and prototype application of information technology to specific bottleneck activities to evaluate potential costs and benefits;
- the investigation and documentation of greater detail in event triggers used in the field for planning, staging, and deployment of labor by superintendents and subcontractors; and
- the development and testing of prototype processes and tools to digitally link field progress to central schedules.

If the goal of this study has been to bridge the gaps between information system requirements and actual construction practices, then the information maps studied here and the overall map presented are steps in the right direction. The incorporation of these ideas into the actual production of houses and into the culture of current American residential construction will be the true test. Any purported benefits will be achieved only then.

Appendix A: List of Documents Used in Study

BUILDER 1

Production Drawings:

12/12 folding roof
7/12 folding roof
roof detail
fireplace detail
first level electric
first level plan
second level plan
floor plan print resolution
folding rafter detail
folding rafter
front elevation
left elevation
rear elevation
right elevation
gable end detail
girder splice detail
insulation procedure
oakstairs detail
plumbing schedule
production procedure
roof framing plan print resolution
roof framing plan screen resolution
walk out bay detail

Production Forms:

drywall order
fixtures order
roof componets (longitudinal) order
inside trim order
roof componets (gable) order
material handling
plant floors
plumbing fixtures order
roof compontets order
shingle order
tow motor schedule 1
tow motor schedule 2
wall componets order

Production Order Forms:

form 1
form 2
form 3
form 4

Contract Of Sale
- request to produce
- form 1
- form 2
- form 3

Quality Control Forms
- form 1
- form 2
- form 3
- form 4
- form 5

Overlays – Electrical
- first level electric
- panel schedule
- production order

Overlays – Plumbing
- plumbers
- plumbing fixtures
- plumbing schematic
- production order

Overlays – Roof Framing
- roof framers
- production order

Overlays – Wall Framing
- wall framers
- walk out bay detail

BUILDER TWO

Customer Order Documentation List
- CIS– Customer Information Sheet
- PA – Purchase Agreement 1 of 5
- PA – Purchase Agreement 2 of 5
- PA – Purchase Agreement 3 of 5
- PA – Purchase Agreement 4 of 5
- PA – Purchase Agreement 5 of 5

Processing Documentation List
- BECAW – Building Energy Conservation Act Warranty
- CDSD– Community Data Sheet Disclosure
- COAD – Concession Addendum
- COR – Change Order Request 1 of 3
- COR – Change Order Request 2 of 3
- COR – Change Order Request 3 of 3
- CR – Condominium Rider
- CUN – Customer Notice (for change orders)
- DIS – Disclosure Statement
- POS – Public Offering Statement & Power of Attorney
- RCA – Radon Contingency Addendum
- SAC – Sales Agreement Checklist
- SOA – Special Option Addendum

Engineering Documentation List

CIS– Customer Information Sheet
COR – Change Order Request 1 of 3
COR – Change Order Request 2 of 3
COR – Change Order Request 3 of 3
CS – Construction Schedule
CSS – Color Selection Sheet
ELS – Electrical Layout Sheet 1 of 2
ELS – Electrical Layout Sheet 2 of 2
FP – Flooring Plan 1 of 2
FP – Flooring Plan 2 of 2
FSS – Flooring Selection Sheet
HBS – House Bible Sheet
JIO – Job Initiation Order 1 of 2
JIO – Job Initiation Order 2 of 2
PEP – Permit Plan
SOA – Special Option Addendum

Contractors' Documentation List

CS – Construction Schedule
FP – Flooring Plan 1 of 2
FP – Flooring Plan 2 of 2
HBS – House Bible Sheet
PEP – Permit Plan
PO – Purchase Order
SUBA – Subcontract Agreement 1 of 2
SUBA – Subcontract Agreement 2 of 2

Production Schedule

Job Initiation Documentation List
CS – Construction Schedule
JIO – Job Initiation Order 1 of 2
JIO – Job Initiation Order 2 of 2

Sub Contractors' and Vendors' Documentation List

COR – Change Order Request 1 of 3
COR – Change Order Request 2 of 3
COR – Change Order Request 3 of 3
CS – Construction Schedule
CSS – Color Selection Sheet
ELS – Electrical Layout Sheet 1 of 2
ELS – Electrical Layout Sheet 2 of 2
FP – Flooring Plan 1 of 2
FP – Flooring Plan 2 of 2
FSS – Flooring Selection Sheet
HBS – House Bible Sheet
JIO – Job Initiation Order 1 of 2
JIO – Job Initiation Order 2 of 2
PEP – Permit Plan
PO – Purchase Order
SOA – Special Option Addendum
SUBA – Subcontract Agreement 1 of 2
SUBA – Subcontract Agreement 2 of 2

Feedback & Archival Documentation List

CBTCR – Community Building Times Comparison Report
CSR – Community Status Report
GPA – Gross Profit Analysis
HBS – House Bible Sheet
SPRF – Sales Price Release Form 1 of 6
SPRF – Sales Price Release Form 2 of 6
SPRF – Sales Price Release Form 3 of 6
SPRF – Sales Price Release Form 4 of 6
SPRF – Sales Price Release Form 5 of 6
SPRF – Sales Price Release Form 6 of 6

BUILDER THREE

Land Acquisition/Site Survey Report
Plan Types for Lots
Site Plan Drawing #1
Site Plan Drawing #2

Lot Status Sheet #1
Lot Status Sheet #2
Lot Status Sheet -Blank

Customer Information Sheet (JIO)
Addendum to Basic Agreement of Sale #1
Addendum to Basic Agreement of Sale #2
Color Selection Sheet

Construction Information
Memorandum
Addendum to Basic Agreement of Sale #1
Addendum to Basic Agreement of Sale #2
Purchase Order for Options/Changes #1
Purchase Order for Options/Changes #2
Purchase Order for Options/Changes #3
Purchase Order for Options/Changes #4
Purchase Order for Options/Changes #5
Building Status Sheet #1

BUILDER FOUR

Pre-defined Sales Packet

- S-1 Artist Rendering
- S-2 Site Map
- S-3 Detailed Site Map
- S-4 Sales Listing
- S-5 The Avery
    - S-5-1 The Avery – Standard
        - S-5-1-A1 Foundation Plan & General Notes
        - S-5-1-A2 Floor Plans
        - S-5-1-A3 Elevations
        - S-5-1-A4 Sections & Details
        - S-5-1-A5 Electrical Plans
    - S-5-2 The Avery – Opposite Hand
        - S-5-2-A1R Foundation Plan & General Notes
        - S-5-2-A2R Floor Plans

S-5-2-A3R Elevations
S-5-2-A4R Sections & Details
S-5-2-A5R Electrical Plans
S-6 The Brandon
S-6-1 The Brandon – Standard
S-6-1-A1 Foundation Plan & General Notes
S-6-1-A2 Floor Plans
S-6-1-A3 Elevations
S-6-1-A4 Sections & Details
S-6-1-A5 Electrical Plans
S-6-2 The Brandon – Opposite Hand
S-6-2-A1R Foundation Plan & General Notes
S-6-2-A2R Floor Plans
S-6-2-A3R Elevations
S-6-2-A4R Sections & Details
S-6-2-A5R Electrical Plans
S-7 The Chelsea
S-7-1 The Chelsea – Standard
S-7-1-A1 Foundation Plan & General Notes
S-7-1-A2 Floor Plans
S-7-1-A3 Elevations
S-7-1-A4 Sections & Details
S-7-1-A5 Electrical Plans
S-7-2 The Chelsea – Opposite Hand
S-7-2-A1R Foundation Plan & General Notes
S-7-2-A2R Floor Plans
S-7-2-A3R Elevations
S-7-2-A4R Sections & Details
S-7-2-A5R Electrical Plans
S-8 The Darden
S-8-1 The Darden – Standard
S-8-1-A1 Foundation Plan & General Notes
S-8-1-A2 Floor Plans
S-8-1-A3 Elevations
S-8-1-A4 Sections & Details
S-8-1-A5 Electrical Plans
S-8-2 The Darden – Opposite Hand
S-8-2-A1R Foundation Plan & General Notes
S-8-2-A2R Floor Plans
S-8-2-A3R Elevations
S-8-2-A4R Sections & Details
S-8-2-A5R Electrical Plans
S-9 Standard Options All Models

Listings, Inspections & Certificates
SS-1 Supplier/ Subcontractors
CCIR-1 Code Compliance Inspection Requests #Lot 13
CCIR-2 Code Compliance Inspection Requests #Lot 11
COUO-1 Certificate of Use and occupancy
SPL-1 Standard Punch List

Change Request Procedure
CRP-1 Customer Change Request
CRP-2 Change Alternative

CRP-3 Change Request to Developer
CRP-4 Approved Change Request – Electrical
CRP-5 Approved Change Request – Electrical
CRP-6 Approved Contract Changes

Construction Packet

CP-1 Standard Pre-defined Packet
CP-2 Approved Change Listing
CP-3 Authorized Work Changes
CP-4 Hardwood Flooring
CP-5 Garage Doors Approved Work Order
- CP-5-1 Garage Door Developer approval
- CP-5-2 Garage Door request for approval

CP-6 Deck Change
CP-7 Paint Selection
- CP-7-1 Paint Selection

CP-8 Plumbing Changes
- CP-8-1 Plumbing Fixture selections
- CP-8-2 Plumbing Change

CP-9 Electrical Changes
- CP-9-1 Electrical Standard
- CP-9-2 Electrical changes from Standard
- CP-9-3 Electrical Light Placement
- CP-9-4 Electrical-Outlet/Switch location changes
- CP-9-5 Electrical change- Cable
- CP-9-6 Electrical change- Phone

CP-10 HVAC
- CP-10-1 HVAC change – Thermostat
- CP-10-2 Fax of written approval for change

CP-11 Appliances
CP-12 Cabinetry

BUILDER FIVE

Sales Documents

B5S01 - Guest Registration Card – front
B5S02 - Guest Registration Card - back
B5S03 - Pinehurst background information
B5S04 - Sales office information
B5S05 - Development Site Map
B5S06 - Standard Features
B5S07 - Letter re standard features
B5S08 - Standard features July 2000
B5S09 - Product sheet front
B5S10 - Product sheet back
B5S11 - Model pricing
B5S12 - Options pricing
B5S13 - Lot availability and premiums
B5S14 – Marked/signed Product sheet
B5S15 - Change order request form
B5S16 - Change order signed
B5S17 – Change order signed product sheet
B5S18 - Buyer information sheet
B5S19 - Pre-construction meeting record

Construction Documents

B5C01 - Boston -electrical plans
B5C02 - Boston -elevations
B5C03 - Boston -floor plans
B5C04 - Boston -wall section details
B5C05 - Lot survey

Administrative Documents

B5A01 - Corp Database Screen Capture
B5A02 - Contract Tracking Spreadsheet
B5A03 - Plans transmittal cover letter
B5A04 - Corporate schedule
B5A05 - Truss/panel contract
B5A06 - Supplier information sheet-a
B5A07 - Supplier information sheet-b
B5A08 - Pricing sheet example 1
B5A09 - Pricing Sheet Example 2
B5A10 - Pricing sheet example 3a
B5A11 - Pricing sheet example 3b
B5A12 - Pricing sheet example 3c
B5A13 - Pricing sheet example 4a
B5A14 - Pricing sheet example 4b
B5A15 - Pricing sheet example 5
B5A16 - Pricing sheet example 6
B5A17 - Homeowner's manual cover
B5A18 - Homeowner's manual index 1
B5A19 - Homeowner's manual index 2
B5A20 - Homeowner's manual index 3

Glossary of Terms

AutoCAD: Computer aided design software, with application in architecture and engineering.

Change Order: A written order to contractor, sign by owner and designer, after the execution of the contract authorizing a change in the work.

Data Elements: Individual pieces of information that make up the information flow.

Dry Runs: Refers to lost time on a construction project derived from delays that impede subcontractors to carry out specified tasks on a previously specified date.

Direct Materials Path: Information flows formally controlled by the production/assembly process

Direct Information Path: Information flows directly involved in the production process.

e-plot: Plans and drawings created in a digital medium.

Enterprise Resource Planning: Information management tools commonly used in manufacturing systems.

Hard Copy Plot: Plans and drawings created on traditional written or paper-based mediums.

High Volume Builders: Contracting firms that build more than 1,000 homes per year utilizing onsite construction methods with a regional or national presence.

Information Model: A procedure for constructing an entity relationship diagram that formally represents the policy and procedures in use by a business.

Information flow: Systematic transmittal of written documents within a pre-established system.

Information filtering: Moments during the information flow in which information is interpreted and modified and transmitted further on the information flow process.

Information Technology: Computer aided technology in general

Information Node: The point at which different information paths converge in a system.

Indirect Information Path: Information flows that are not directly involved in the production process.

Indirect Materials Path: Information flows which are not formally controlled by the production/assembly process.

Milestone Events: Activities that signify that commencement or ending of essential events in a construction schedule.

Medium Volume Builders: Contracting firms that build up to several hundreds of homes per year in regional markets.

Object-Orientated database: Attribute traditional database information and specification information to data elements.

Object-Oriented CAD: Attribute traditional database information and specification information to object drawings.

Parametric design: The linkage of three-dimensional models with two-dimensional plans. In an ideal system, it indicates information paths and material paths.

Production builders: Construction companies that use off-site fabrication, including modular and factory based panelizers undertaking the majority of their work in a factory environment.

Process Map: A graphical representation of data, document, management and field relationships.

Regulations: Usually a rule promulgated by administrative agency pursuant to authority delegated to it by legislation.

Site Factory: Construction site that use assembly line production type.

Small Volume Builders: Contracting firms building fewer than 20 homes per year.

Trigger Action-Event: A set of circumstances that set up a chain of events.

Web Base System: Software or administration tools that use a world wide web or internet platform.